

THE ULTRAVIOLET EMISSION PROPERTIES OF FIVE LOW-REDSHIFT ACTIVE GALACTIC NUCLEI AT HIGH SIGNAL TO NOISE AND SPECTRAL RESOLUTION ¹

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ABSTRACT

We analyze the ultraviolet (UV) emission line and continuum properties of five low-redshift active galactic nuclei (four luminous quasars: PKS 0405–123, H1821+643, PG 0953+414, and 3C273, and one bright Seyfert 1 galaxy: Mrk 205). The HST spectra have higher signal-to-noise ratios (typically ~ 60 per resolution element) and spectral resolution ($R = 1300$) than all previously-published UV spectra used to study the emission characteristics of active galactic nuclei. We include in the analysis ground-based optical spectra covering $H\beta$ and the narrow [O III] $\lambda\lambda 4959, 5007$ doublet.

The following new results are obtained: $Ly\beta/Ly\alpha=0.03-0.12$ for the four quasars, which is the first accurate measurement of the long-predicted $Ly\beta$ intensity in QSOs. The cores of $Ly\alpha$ and C IV are symmetric to an accuracy of better than 2.5% within about 2000 km s^{-1} of the line peak. This high degree of symmetry of $Ly\alpha$ argues against models in which the broad line cloud velocity field has a significant radial component. The observed smoothness of the $Ly\alpha$ and C IV line profiles requires at least $\sim 10^4$ individual clouds if bulk velocity is the only line-broadening mechanism. The overall similarity of the $Ly\alpha$ and C IV $\lambda 1549$ profiles rules out models for the broad line region (BLR) with a radial distribution of virialized clouds having an ionization parameter $U \propto \text{Radius}^{-1}$. The measured high values of O VI $\lambda 1034/Ly\alpha$ and low values of C III $\lambda 977/O \text{ VI } \lambda 1034$ imply a BLR component with $U \sim 1$. The excess red-wing flux in O VI relative to $Ly\alpha$ suggests the presence of an inner, high-velocity, optically-thin component with $U > 1$ in the BLR.

The N V/ $Ly\alpha$ ratio is 0.135 ± 0.01 for the four quasars, which may be an indication of higher-than-solar N abundance and metallicity. The maximum contribution of a narrow ([O III]-like) component is about 3–6% of the total broad line flux; this limit is generally highest for C III]. This result constrains the covering factor of the narrow line region or indicates the presence of dust. An unresolved component having full width at half maximum $< 230 \text{ km s}^{-1}$ typically contributes less than 0.5% of the observed broad lines flux. The HST data permit the first relatively accurate measurements of the $Ly\gamma$, C III $\lambda 977$, S VI $\lambda\lambda 933, 945$, and the N III $\lambda 991$ emission lines, as well as the measurement of a number of other weak or strongly blended lines at $\lambda > 1216 \text{ \AA}$.

In agreement with observations of high-redshift quasars, the peaks of $Ly\alpha$, C IV, and C III] are blueshifted by $\sim 200 \text{ km s}^{-1}$ relative to [O III] $\lambda 5007$, while He II $\lambda 1640$ is shifted by about 500 km s^{-1} . The low ionization lines, Mg II, $H\beta$, and O I $\lambda 1304$, are in most cases only marginally shifted to the red.

Subject headings: galaxies:nuclei—galaxies:Seyfert— ultraviolet: spectra—line profiles—quasars

1 INTRODUCTION

This paper analyzes the emission properties of low-redshift active galactic nuclei (AGNs) observed with the *Hubble Space Telescope* (HST) at a high signal-to-noise ratio S/N ($\gtrsim 60$ per resolution element) and a relatively high spectral resolution ($\sim 230 \text{ km s}^{-1}$). We study the spectra of four low-redshift quasars ($0.157 \leq z \leq 0.573$): PKS 0405–123, H1821+643, PG 0953+414, and 3C273, which have luminosities in the range $-28.4 \leq M_V \leq -25.5$ (for $H_0=50 \text{ km s}^{-1}$, $q_0=0$) and Mrk 205, a bright Seyfert 1 galaxy with $M_V = -22.9$. We use objective algorithms for modeling and deblending the emission line profiles. The results presented here can help determine the physical and dynamical conditions near the centers of AGNs.

The ultraviolet (UV) emission properties of low-redshift AGNs have been studied previously with the International Ultraviolet Explorer (IUE) (e.g. Green *et al.* 1980; Ulrich *et al.* 1980; Kinney *et al.* 1985, 1987). These observations have a spectral resolution of 6 \AA , i.e. 1000 km s^{-1} at $\lambda = 1800 \text{ \AA}$. The small IUE mirror size allows high (S/N) observations to be obtained only for the brightest AGNs, and the observations are further limited by the presence of systematic variations in the detector calibration at a level of 5% or more (e.g. Kinney *et al.* 1991). High S/N observations at a higher spectral resolution for quasars are available only through ground-based observations of high-redshift objects. These high-redshift studies are strongly affected at $\lambda_{\text{rest}} \leq 1216 \text{ \AA}$ by absorption from the Ly α forest systems.

The present analysis provides new information on the emission line regions of low-redshift AGNs. In particular:

1. At $\lambda_{\text{rest}} < 1216 \text{ \AA}$, we study low-redshift AGNs without significant distortion by intervening absorption systems. This allows us to make accurate measurements of the degree of asymmetry of the Ly α emission line, of the width of the O VI line, of the contribution of Ly β to the O VI+Ly β blend, and of the flux in C III $\lambda 977$ +Ly γ and N III $\lambda 991$.
2. At $\lambda_{\text{rest}} > 1216 \text{ \AA}$, we study in detail the profiles of the prominent UV emission lines and measure the flux in very weak UV emission lines. This was previously possible only using ground-based observations of high-redshift quasars.

The outline of this paper is detailed below. In §2, we describe the observations and data reduction, and in §3 we outline the line and continuum fitting procedures. The results are presented in §4. In §5, we compare the line ratios we measure here with IUE observations of low-redshift AGNs and with ground-based observations of high-redshift quasars. In §6, we compare our results for the line profiles with previous studies and discuss the theoretical implications. In §7, we compare our results for the line ratios with recent theoretical predictions and discuss some of the theoretical implications. We conclude in §8 with a summary of our main results. The technical details of the line-fitting procedures are given in the Appendix.

2 OBSERVATIONS

2.1 *The HST Observations*

We observed five AGNs using the R=1300 gratings of the Faint Object Spectrograph (FOS). Table 1 lists the five objects in our sample, together with their J2000 positions, redshift, V and M_V magnitudes (calculated for $H_0=50 \text{ km s}^{-1}$, $q_0=0$), Galactic reddening, and the papers that analyzed the absorption line properties of these objects using HST data. The coordinates were measured with the Space Telescope Science Institute's Guide Star Selection System Astrometric Support Package and should be accurate to $\simeq 1''$. The V magnitudes are from the Véron-Cetty & Véron (1991) catalog. The redshifts were measured using [O III] $\lambda 5007$, as further described below. The reddening is deduced from the neutral hydrogen column density N_H (taken from Stark et al. 1992), and the $E(B-V)$ vs. N_H relation given by Burstein & Heiles (1982). The alternative $E(B-V)$ vs. N_H relation found by Savage & Mathis (1979) implies a significantly higher Galactic extinction, in particular for PKS 0405–123, where the Savage & Mathis relation gives $E(B-V)=0.078$ instead of 0.031, and also for H1821+643, where $E(B-V)=0.083$ instead of 0.035. Applying these higher, but equally plausible, reddening corrections would result in a factor of about two higher flux at the shortest UV wavelengths. More accurate N_H measurements for 3C273 and H1821+643 are given by Savage *et al.* (1993), who find N_H values higher than the Stark *et al.* values by 8% and 4%, respectively; these differences, however, are negligible in comparison with the large uncertainty present in the N_H to $E(B-V)$ conversion relation mentioned above.

Table 2 lists the dates of the observations, the gratings and aperture used, and exposure times for each object. All observations were made through the $0.25'' \times 2.0''$ slit except for 3C273, where we have also added exposures made through the $0.3''$, $0.5''$, and $1.0''$ circular apertures. The wavelength ranges covered by each grating are 1150 Å–1606 Å for the G130H, 1600 Å–2310 Å for the G190H, and 2230 Å–3280 Å for the G270H. The dispersions in the G130H, G190H, and G270H data are respectively 0.25, 0.36, and 0.52 Å pixel $^{-1}$, with approximate spectral resolutions (full width at half maximum) of 1.1 Å, 1.5 Å, and 2.0 Å for the three gratings. Further details concerning the instrumental configuration and the data calibration are described in Schneider *et al.* 1993, and in Bahcall et al. (1991, 1992a,b, 1993a,b). The long exposure times combined with the high UV flux of all the objects produced a S/N per resolution element in the range of 25 – 120, with a typical value of ~ 60 . The spectrum of PKS 0405–123 extends to the shortest rest wavelength ($\lambda_{\text{rest}} \sim 730 \text{ Å}$). The spectrum of Mrk 205 extends to the longest rest wavelength, ($\lambda_{\text{rest}} \sim 3050 \text{ Å}$), but we have no FOS data for this object for $\lambda_{\text{rest}} < 1500 \text{ Å}$. The data for 3C273 has a gap at $1380 \text{ Å} < \lambda_{\text{rest}} < 1420 \text{ Å}$ (Bahcall *et al.* 1991) which makes the O IV] $\lambda 1402$ +Si IV $\lambda 1397$ blend unobservable.

2.2 *Ground-Based Observations*

We have obtained ground-based optical spectroscopy including the $H\beta$ $\lambda 4861$ + [O III] $\lambda 5007$ lines for all objects. Most of these spectra have a similar resolution and S/N as the UV data. All objects, except for PKS 0405–123, were observed at the Kitt Peak National Observatory 4-m telescope. The observations of 3C273 and PG 0953+414 are described in Boroson & Green (1992). Mrk 205 was observed on 28 April, 1992, with the R-C spectrograph on the Kitt Peak 4-meter telescopes. The B&L 400 grating and TI 5 CCD gave coverage from 4900 to 7600 Å at 12 Å resolution. The quasar H 1821+643 was observed on August 20th, 1992, with the Kitt Peak 2.1-m telescope and Goldcam CCD spectrograph. Grating 240, ruled at 500 l/mm, gave coverage from 4400 to 9000 Å, with 4.5 Å resolution. A high S/N optical spectrum of PKS 0405–123, extending from 3100 to 8700 Å, was kindly supplied to us by B. Wills (published in Wills, Netzer & Wills 1985). The optical and UV flux densities of PKS 0405–123 in the overlap region of the spectra (~ 3250 Å) agree to better than 6%, even though these observations were made 9 years apart. We were not able to intercalibrate the optical and UV spectra for the other 4 objects due to lack of overlapping coverage. The Fe II optical blends were subtracted from the optical spectra of all the objects using the template method applied by Boroson & Green (1992) for PG 0953+414 and 3C273.

The optical spectroscopy is used for the following purposes: 1. To define the redshifts of all objects in a uniform manner using the peak of the narrow [O III] $\lambda 5007$ emission line. 2. To make a template for the profile of the narrow emission line component using the [O III] $\lambda 5007$ line. 3. To compare the low-ionization $H\beta$ profile to that of the high-ionization UV lines.

3 THE LINE AND CONTINUUM FITTING METHOD

In order to extract the information present in the emission line spectra, we have developed a specific line-fitting method which has the following characteristics: 1. It implements an objective algorithm. 2. Spectral regions possibly affected by narrow absorption lines can be identified and rejected from the fit. 3. It produces a smooth model for the intrinsic emission-line profiles and allows an accurate measurement of the integrated emission fluxes. 4. The fit parameters can be physically interpreted as integrated flux, velocity shift, and velocity dispersion.

Below we review briefly the details of the fitting method; complete details are given in the Appendix. The first step is to define the continuum. A smooth continuum model, e.g. a single power-law, cannot follow the apparent continuum level to better than $\sim 10\%$, due to the presence of very broad and low level emission features. We avoid modeling these features by making local continuum fits. Each spectrum is divided into sections that are about ~ 200 Å wide, centered around the prominent emission features. For each section the local continuum is defined

as a power-law that intersects the spectrum at the two end points. We model the observed emission line profiles as a sum of Gaussians components and we use a χ^2 minimization routine to obtain the best fit parameters. We found that at least three Gaussians were required to obtain an acceptable model fit for the prominent UV line profiles (Ly α , C IV, and C III]), and one Gaussian was usually sufficient for weak or strongly blended lines (e.g. N V). Each Gaussian is defined by three parameters, and the initial guess for the values of these parameters is obtained by measuring the zeroth, first, and second moments of the flux distribution within a given section of the emission line. For the three Gaussians used to model the prominent lines, the initial guess for the fit parameters is obtained by measuring the moments of the flux in the lower, middle, and upper section of the line. For the single Gaussian component which models a blended line, we measure the flux moments within 10 Å of the rest wavelength of the line. The best fit values obtained following the χ^2 minimization are generally not very far from the initial guess values, in particular when the profile is characterized by a high S/N and is not significantly affected by absorption.

In some cases, it is possible to obtain an acceptable fit to the profile of a blend using a sum of template line profiles. We constructed a symmetric template profile using the blue wing of Ly α , and used it to deblend the O VI, Ly α , and C IV blends in three of our five objects. This method is used to test the significance of the apparent differences in the line profiles, and also to get a better estimate of the flux in some of the strongly blended lines (e.g. N V, Ly β). Further details are given in §4.2.5 and in the Appendix.

4 RESULTS

4.1 *The Continuum*

Figure 1 displays the spectra of the five objects. The spectra are shown on rest wavelength scales; they are corrected for Galactic reddening using the extinction values given in Table 1 and the reddening law of Seaton (1979). To improve the presentation, the displayed spectra were smoothed by median filtering over 21 pixels (except near the peaks of the prominent lines).

The average spectrum of ~ 700 quasars observed from the ground by Francis et al. (1991, hereafter the Francis *et al.* composite) is also shown for comparison in each panel. Note the overall similarity of the continuum slopes at $\lambda \gtrsim 1300$ Å and of the various emission features between each of our objects and the Francis *et al.* composite, which represents significantly higher redshift ($z \sim 1 - 2$) quasars. The large discrepancy shortward of Ly α is most probably due to unresolved Ly α absorption systems which depress the continuum level in the Francis et al. composite. There is a broad emission feature in all spectra on the red side of C IV $\lambda 1549$ at $\lambda \sim 1600$ Å; this feature is particularly strong in H1821+643.

The spectral slope, $\alpha = d \ln F_\nu / d \ln \nu$, between adjacent continuum windows is given for each object in Table 3. Note the large and non-monotonic variations of α with wavelength for each object. These variations indicate, as mentioned in §3 and §A.1, the presence of broad quasi-continuum emission features in the spectra.

4.2 The Lines

Figures 2a-e show the spectra of each of the five objects in detail. The spectra were smoothed with a Gaussian as discussed in §A.2. For the sake of clarity, all points with $\Delta < -3.0$ were deleted from the plotted spectra, where Δ is the deviation from the median in units of standard deviations (see §A.2). The spectra of all objects are plotted in parallel to facilitate their intercomparison. We indicate the rest wavelength positions of most lines that have been observed in the past or that were predicted to be present in AGNs. Most lines are composed of several components, as indicated in each panel; the effective wavelengths of these multiplets are taken from Morton (1991). A large number of weak continuum features are apparent in each spectrum. Weak emission features were measured only if they appear in more than one object and if they have a plausible identification (i.e. were clearly identified in other objects, or are expected based on the presence of other emission lines). A large number of broad emission features are present at $\lambda > 2000 \text{ \AA}$; most are likely to be blends of Fe II multiplets, as shown by Wills, Netzer & Wills (1985). The effects of blendings are minimized in narrow-line quasars. Therefore the broad and blended emission features can be optimally studied by using a narrow line quasar spectrum as a template, as done by Boroson & Green (1992) for the optical Fe II emission blends; however, such a template is not yet available in the UV.

4.2.1 Line Deblending

The four prominent blends in the spectrum of each object are: 1. O VI+Ly β +N III+C III+Ly γ , 2. Ly α +N V+O I+C II, 3. C IV+He II+O III]+N IV], and 4. C III]+Si III]+Al III. These lines were deblended using the algorithm described in §A.2. No FOS data at $\lambda_{\text{rest}} < 1600 \text{ \AA}$ are available for Mrk 205; for this object we fitted the C IV and C III] blends, and Mg II $\lambda 2798$.

Figures 3a-e display the sequence of fits that leads to the line deblending results. The formal χ^2 of the fit and the number of degrees of freedom are indicated in each panel. The value of χ^2 only serves to indicate the average level of deviation of the data from the best fit model, rather than to measure the statistical significance of the fit (see §A.2). The continuum level is not well determined on the blue side of O VI+Ly β due to the complicated continuum shape in that region. In two objects, PG 0953+414 and 3C273, the continuum underlying O VI+Ly β is set by extrapolation of the slope measured at longer wavelengths. Since the observed continuum slope in the UV tends to steepen towards shorter wavelengths (e.g. O’Brien, Gondhalekar, & Wilson

1988), this extrapolation might underestimate the true flux in the blue wing of O VI+Ly β , and produce the very asymmetric broad wings of O VI+Ly β in PG 0953+414 and 3C273 (Figs. 3.c,d).

Table 4 gives the best fit parameters for each of the prominent blends displayed in Figs. 3.a-e, and a number of other lines/blends; the errors in the fit parameters are also given. The fluxes given in Table 4 are in the observed frame, and the values of the EW is given in the rest frame, i.e. it is equal to the observed EW divided by $(1+z)$. Adding the superscript error of each parameter gives the value obtained for the fit with the continuum displaced upwards by 1σ , and adding the subscript error gives the value obtained with the continuum displaced downwards by 1σ (see §A.2). As mentioned above, these two errors do not always have opposite signs. The 9 parameters (of the 3 Gaussians) obtained from the fit to the prominent lines can be useful when making a statistical study of the line profiles of a larger sample of objects.

4.2.2 *The Apparent Line Asymmetry*

Figure 4 displays the asymmetry of the Ly α and C IV blends. We show the ratio of the red ($+v$) to blue ($-v$) wing flux in the best-fit model as a function of velocity from the line peak. The line peak is defined using a parabola fitted to the three highest flux points in the best fit model. We plot the ratio of the fit to the observed profiles, rather than the deblended Ly α and C IV profiles, since any deblending procedure is model dependent. In almost all cases both Ly α and C IV display a generally similar behavior of an increasing red to blue wing flux ratio with increasing velocity from the line center. Ly α has a symmetric core in two objects and C IV in three objects. In both 3C273 and PG 0953+414 this ratio deviates by less than 5% from unity out to a velocity of $\sim 2000 - 2500 \text{ km s}^{-1}$ from the line peak. The C IV profile is generally more symmetric than Ly α . The symmetry of Ly α is further addressed below in §6.4.

Figure 4 also shows the expected asymmetry in the case of a cloud distribution which is spherically symmetric in both position and velocities, and assuming each cloud emits isotropically. The asymmetry in this case results from special relativistic beaming which enhances the blue wing emission. In all cases, except C IV in Mrk 205, the observed asymmetry has the opposite sense.

4.2.3 *Comparison of the Line Profiles*

Figure 5 compares the fitted models for the profiles of the blends of O VI, Ly α , C IV, C III], H β (with the Fe II subtracted), and the narrow [O III] $\lambda 5007$ line, for all objects. The profiles of all lines are scaled such that the maximum flux density of the model fit is at 1. The O VI blend has the broadest profile in all four quasars, having an average FWHM= $5148 \pm 432 \text{ km s}^{-1}$ (dispersion from mean, see specific values in Table 4), which is about 50% larger than the average FWHM= $3514 \pm 569 \text{ km s}^{-1}$ of C IV. The FWHM of Ly α is $3014 \pm 432 \text{ km s}^{-1}$, which is the

smallest of the broad emission lines. The significance of these profile differences is addressed below (§4.2.5)

In all objects, except H1821+643, C III] has the narrowest peak. In all cases, Ly α is narrower than C IV, except for the broad wings, where it is comparable to C IV. The broad wings of O VI are significantly asymmetric in 3C273 and in PG0953+414. This could be due to errors in the extrapolated continuum shape, as mentioned above (§4.2.1). The H β line has a significant red wing excess in PKS 0405–123 and in H1821+643, and its peak in all objects appears to coincide well with the peak of [O III] λ 5007. The spectrum of H1821+643 is different from the spectra of the other four objects in that all of its emission lines are strongly asymmetric, having a strong red excess. The largest asymmetry in the spectrum of H1821+643 occurs in the H β profile. A similar asymmetry is apparent in the other Balmer lines (Kolman *et al.* 1991).

Table 5 gives the velocity shifts of the lines. The observed wavelength of a line is defined by the position of the peak of the fitted model. In a few cases, the observed line profile near the peak is asymmetric, and the fitted model peak can somewhat deviate from the observed peak (most notably in the fit of O VI in H1821+643, Fig.3b). The velocity shifts are measured relative to the rest wavelengths of Ly α , C IV, C III] and O VI (given in Table 4). All lines, except O VI+Ly β in PG 0953+414 and 3C273, are shifted by less than 300 km s $^{-1}$. The low ionization lines, H β and Mg II, are generally only slightly shifted, in most cases to the red, while the high ionization lines are generally blueshifted. Note that the HST absolute wavelength calibration is defined by a system in which the strong interstellar absorption lines in the direction of each object are at rest, while the optical redshifts are measured with respect to the local standard of rest (LSR). This can introduce systematic velocity shifts of up to ~ 60 km s $^{-1}$ between the optical and UV redshifts (Bahcall *et al.* 1993b, Savage *et al.* 1993).

4.2.4 The Narrow-Line contribution

Table 6 presents the maximum possible contribution of a narrow [O III]-like component to the total flux in the prominent UV lines and in H β for each object. This contribution is measured by repeating the fitting process described in §A.2 with the further constraint that the velocity dispersion of the third (narrowest) component be equal to that of [O III] λ 5007, as measured for each object. The FWHM of [O III] is also given in Table 6. This added constraint results in a small increase in χ^2 compared with the minimum value obtained when all parameters are allowed to vary. The largest contribution of a narrow-line-like component generally occurs in Ly α and C III], and the lowest in O VI. The peaks of some of the emission lines are visibly affected by absorption (e.g. Ly α in PG0953+414). In these cases, the intrinsic line profile near the peak is probably narrower than given in Table 6, and the maximum possible flux in a narrow component is probably larger.

In order to estimate the maximum possible flux in a spectrally unresolved component, we have repeated the fitting of the upper part of each line. We used the observed, rather than the Gaussian smoothed spectrum, and measured the flux of the narrowest component which was forced to have a FWHM of 230 km s^{-1} (i.e. $R=1300$). We find the upper limit on the flux in an unresolved component is generally less than 0.5% of the total line flux, and it is typically about 0.1–0.2%. Only in one case, the C III] profile of PG 0953+414, is the unresolved component as large as 1.3%. Thus practically all of the observed emission line flux is well resolved.

4.2.5 *Line-fitting with a template*

As mentioned above (§4.2.3), O VI is broader (in FWHM) than Ly α by $\sim 2100 \text{ km s}^{-1}$, on the average, and C IV is broader than Ly α by 500 km s^{-1} . However, it is not clear a priori whether the broader O VI and C IV profiles reflect larger velocity dispersions, or just the fact that both these lines are doublets. In the C IV doublet (1548.20\AA , 1550.77\AA), the equivalent velocity separation of the two components is 499 km s^{-1} , and in O VI (1031.93\AA , 1037.62\AA) it is 1651 km s^{-1} . O VI is also strongly blended with Ly β (1025.72\AA) at a velocity separation of 2348 km s^{-1} from the mean O VI wavelength. In order to test whether C IV and O VI are intrinsically broader than Ly α , we use the Ly α profile as a template to fit the doublet lines. One cannot just use the observed Ly α profile since its red wing is strongly blended with N V. We therefore use only the blue wing of Ly α to form a “symmetric Ly α ” template, and use this symmetric profile to fit the observed Ly α , O VI and C IV blends (see §A.4. for further details on the fitting procedure).

Figure 6 presents the template fits. The χ^2 , the number of degrees of freedom, and the velocity range over which the fit was made, are indicated in each panel. We do not attempt to fit the blue wing of O VI beyond 2000 km s^{-1} , nor the blue wing of C IV beyond $1000\text{--}2000 \text{ km s}^{-1}$. The best fit parameters (flux and velocity shift) are given in Table 7. For each emission line we give two results, the upper row is obtained when we assume the ratio of fluxes of the components of a multiplet are the same as their statistical weight ratio, and the parameters in the lower row are obtained assuming equal weights for all multiplet components. We arbitrarily fixed the velocity shifts of Ly β and Ly γ at the best fit value of Ly α , while for other weak components we generally assumed a zero velocity shift. We did not include Mrk 205 in the fits since the Ly α profile is not available for it; we also do not include H1821+643, since all its emission lines are strongly asymmetric and the “symmetric Ly α ” template cannot provide an acceptable fit. We attempted to deblend the C III] blend using the template method, however, in all cases C III] has a significantly narrower peak than our template (see Fig.5), and an acceptable fit could not be obtained.

The core of the O VI blend is well fit with the “symmetric Ly α ” template, essentially all the difference in FWHM between Ly α and O VI can be explained by the wide separation of the O VI

doublet and some additional blending with $\text{Ly}\beta$. However, in every case there is a significant excess in the red wing of O VI compared with the “symmetric $\text{Ly}\alpha$ ” best fit. The peak of the O VI blend is not well fit in PKS 0405–123 and PG 0953+414, and it is not clear whether the effects of absorption can account for the magnitude of the observed differences.

The red wing of C IV cannot be fit by the template, possibly due to the ~ 1600 Å emission feature (see §5.1.7). The peak of C IV is narrower than the template, although $\text{Ly}\alpha$ in the case of PG 0953+414 is clearly self-absorbed, and the intrinsic $\text{Ly}\alpha$ profile can have a stronger narrow peak than deduced here.

Figure 7 presents a template fit to the Si IV+O IV] blend. The Si IV was modeled as a doublet at 1393.76 and 1402Å, with a 2:1 flux ratio. The O IV] multiplet was modeled with 5 components at 1397.23, 1399.78, 1401.16, 1404.81, and 1407.38Å, and a 2:1:6:4:2 flux ratio (see Morton 1991). For each object we present two possible fits with different Si IV/O IV] ratios, and assuming both multiplets are at rest with respect to [O III] $\lambda 5007$. We do not measure the formal best-fit ratio since the blend profile has a rather low S/N, and the Si IV/O IV] ratio cannot be accurately determined.

5 COMPARISON WITH PREVIOUS OBSERVATIONS

5.1 Line Ratios

We describe in this section the first measurements of a number of far UV ($\lambda < 1000$ Å) emission lines and many weak UV lines (such as O I $\lambda 1303$, C II $\lambda 1335$, O III] $\lambda 1664$, and N III] $\lambda 1750$) which were previously measured only in high-redshift AGNs (e.g. Baldwin & Netzer 1978; Uomoto 1984).

5.1.1 S VI $\lambda 937$, C III $\lambda 977$ + $\text{Ly}\gamma$, and N III $\lambda 991$

The two components of the S VI $\lambda 937$ doublet (933.38, 944.52Å), are detected in the spectrum of PKS 0405–123 (Fig.2a). The S VI emission has not been previously detected in the spectrum of an individual AGN. This line was detected in a composite IUE spectrum of 22 low-redshift quasars derived by Sofia, Bruhweiler & Kafatos (1988), but the two components of the line were not resolved and their flux was not measured. We note that the S VI $\lambda 937$ doublet was also recently detected in absorption in the broad absorption line quasar 0226 –1024 by Korista *et al.* (1993) in data taken with the HST FOS.

We measure line flux ratios C III+ $\text{Ly}\gamma$ / $\text{Ly}\alpha$ =0.056–0.064 in the spectrum of PKS 0405–123 (Table 7) and 0.024 in the spectrum of H1821+643 (Table 4). The C III+ $\text{Ly}\gamma$ blend has not been accurately measured before in quasars. The only two papers we are aware of that measure

this blend in individual quasars are by Wilkes (1986), who found C III $\lambda 977 + \text{Ly}\gamma / \text{Ly}\alpha = 0.04$ in one high-redshift radio selected quasar (PKS 1614+051), and Green *et al.* (1980), who observed this line with the IUE in two quasars (PKS 1302 -102, and PG 1247 +268), and found C III $\lambda 977 + \text{Ly}\gamma / \text{Ly}\alpha = 0.084$ and 0.105. Note that the Green *et al.* ratios are likely to be significantly biased towards high values since the low S/N of the IUE spectra allowed detection of the C III $\lambda 977 + \text{Ly}\gamma$ blend in only two of their five objects. The C III+ $\text{Ly}\gamma$ blend was also recently measured in the Seyfert 2 galaxy NGC 1068 by Kriss *et al.* (1992) using the Hopkins UV Telescope (HUT), where a ratio of C III $\lambda 977 + \text{Ly}\gamma / \text{Ly}\alpha = 0.06$ was obtained.

The C III+ $\text{Ly}\gamma$ blend in PKS 0405-123 is visibly asymmetric (Figs.2a and 7), suggesting a significant $\text{Ly}\gamma$ contribution. Our best fit template deblending (Table 7) suggests $\text{Ly}\gamma / \text{C III} \sim 1/3$, or $\text{Ly}\gamma / \text{Ly}\alpha = 0.017$. The C III $\lambda 977 + \text{Ly}\gamma$ blend is also observed in the spectrum of H1821+643; however, the spectrum in this object appears to have a discontinuity at 973 Å and no $\text{Ly}\gamma$ contribution is apparent.

We measure N III $\lambda 991 / \text{Ly}\alpha$ ratios of 0.013, 0.014, and 0.0085, in PKS 0405-123, H1821+643 and PG 0953+414. The N III $\lambda 991$ line has not been previously detected in an individual quasar spectrum. It was detected but not measured in the IUE composite spectrum of Sofia, Bruhweiler & Kafatos (1988). This line was recently detected in the Seyfert 2 galaxy NGC 1068 by Kriss *et al.* (1992), who found N III $\lambda 991 / \text{Ly}\alpha = 0.031$.

A particularly large systematic error is possible in our measurements of the fluxes in S VI, N III and C III, due to the low EW of these lines, the presence of narrow absorption lines, and the uncertainty in the continuum placement at $\lambda < 1000$ Å. In the analysis presented above and in the following sections, we use the line fluxes from Table 7 when available, rather than Table 4, as the Table 7 values are likely to be more realistic.

5.1.2 O VI $\lambda 1034 + \text{Ly}\beta$

We measured an average line flux ratio O VI $\lambda 1034 + \text{Ly}\beta / \text{Ly}\alpha + \text{N V} = 0.34 \pm 0.13$ (the error here and below is the dispersion about the mean). The O VI+ $\text{Ly}\beta$ blend has been measured in intermediate redshift quasars using the IUE (e.g. Green *et al.* 1980; Gondhalekar O'Brien & Wilson 1986; Kinney *et al.* 1987) and in high-redshift quasars using ground-based observations (e.g. Baldwin & Netzer 1978; Wilkes 1984, 1986; Steidel & Sargent 1987). In intermediate redshift quasars, O VI+ $\text{Ly}\beta / \text{Ly}\alpha + \text{N V} = 0.24 \pm 0.07$ [using the measurements of 13 quasars with $z \sim 0.3 - 0.75$ made by Kinney *et al.* (1985, 1987)]. The IUE measurements are likely to miss some of the flux in the broad wings of the O VI+ $\text{Ly}\beta$ blend due to the typically very low S/N of the IUE spectra. Our higher O VI+ $\text{Ly}\beta / \text{Ly}\alpha + \text{N V}$ ratio may therefore be more realistic.

In radio selected high-redshift quasars O VI+ $\text{Ly}\beta / \text{Ly}\alpha + \text{N V} = 0.18 \pm 0.11$ (using the measurements of Wilkes 1986). A very similar ratio, 0.17 ± 0.09 , is obtained for optically selected

high-redshift quasars (Osmer & Smith, 1976), and it therefore appears that our small sample of low-redshift quasars is significantly different from high-redshift quasars. However, Osmer & Smith measured the flux only within $\pm 5000 \text{ km s}^{-1}$ of the O VI+Ly β blend center, and they therefore excluded most of the flux in the broad component of this blend. Repeating our measurements, with the broad component of the O VI+Ly β blend excluded, we find O VI+Ly β /Ly α +N V = 0.15 ± 0.05 , which is consistent with the high-redshift quasars ratio. Given the lower S/N and the large number of Ly α absorption systems which affect the high-redshift quasars spectra, one cannot rule out the presence of a significant flux in a broad component (FWHM $\sim 20,000 \text{ km s}^{-1}$) of O VI in high-redshift quasars, as found here in low-redshift quasars. It is therefore possible that the apparent difference in the O VI+Ly β /Ly α +N V ratio between high and low-redshift quasars just reflects the difference in data quality and measurement methods, rather than being a real physical difference.

We find Ly β /O VI ratios of 0.25, ~ 0.10 , 0.27, and 0.35 for PKS 0405–123, H1821+643, PG 0953+414 and 3C273, using the template deblendings (given in Table 7), where for H1821+643 we estimated the Ly β fraction by following the template deblending procedure using the observed C IV profile. These four values are likely to overestimate the intrinsic Ly β /O VI ratio since the template fitting of O VI does not include a significant amount of flux in the red wing of O VI (Fig.6). When this flux is added (as calculated from the integrated O VI blend flux given in Table 4), the revised values are: 0.16, ~ 0.10 , 0.14, and 0.28. These ratios were obtained assuming the 2:1 multiplet ratio in O VI, and a zero O VI velocity shift. Somewhat lower ratios are obtained assuming a multiplet ratio of 1:1 in O VI, in which case O VI must be blueshifted (see Table 7). Very few attempts have been made in the past to deblend Ly β from O VI. Wilkes (1984) used the C IV line profile to deblend Ly β from O VI in two high redshift quasars, and found Ly β /O VI ratios of 0.31 and 0.46.

Using the template deblendings (Table 7) we find Ly β /Ly α =0.033, 0.030, 0.066, and 0.12 in PKS 0405–123, H1821+643, PG 0953+414 and 3C273. Similar values, Ly β /Ly α =0.06, 0.10, were found in two high-redshift quasars by Wilkes (1984).

5.1.3 Ly α +N V $\lambda 1240$ +Si II $\lambda 1263$

The range of Ly α rest-frame EW, 51 Å–136 Å, found here is typical for the luminosity range of $-28.4 \leq M_V \leq -25.5$ of our four quasars (e.g. Netzer, Laor, & Gondhalekar 1992). We therefore do not expect our objects to be very peculiar in terms of their emission line properties.

A rather small dispersion is found in the N V/Ly α line ratios. We measure N V/Ly α =0.13, 0.12, 0.14, and 0.15 for PKS 0405–123, H1821+643, PG 0953+414 and 3C273 (using Table 7 in all objects except H1821+643, where we use Table 4). Very little data is available on the N V/Ly α ratio in low-redshift AGNs, since the low quality of the IUE spectra did not allow N V

to be reliably deblended from $\text{Ly}\alpha$. Green *et al.* (1980) found ratios of 0.04, 0.039, and 0.17 in the IUE spectra of PKS 0405–123, PG 0953+414, and PKS 1302–102. Kinney *et al.* (1985) quotes an average value of 0.15 for 8 objects out of 21, but they do not give further details.

In high redshift quasars $\text{N V}/\text{Ly}\alpha=0.32\pm0.13$, using the Wilkes (1986) measurements of N V in 34 objects (see similar values in Osterbrock 1989; Netzer 1990). The formal error in the mean value for high redshift quasars is ±0.02 , and it therefore appears to deviate significantly from the value found here for low-redshift AGNs. It is, however, possible that the N V/Ly α ratio in high-redshift quasars has been systematically overestimated. This can result from an underestimate of the intrinsic flux in the Ly α red wing, which might happen if this estimate is influenced by the shape of the Ly α blue wing, which is significantly absorbed in high-redshift quasars (see Wilkes 1986).

We find Si II $\lambda 1263/\text{Ly}\alpha=0.026$, 0.018, and 0.053 for PKS 0405–123, PG 0953+414, and 3C273, using the template deblending scheme (Table 7, note that the detection in PG 0953+414 is very marginal). Apart from 3C273, the Si II $\lambda 1263$ blend was not measured in other low-redshift AGNs. We note, however, that this blend can be clearly discerned in some of the IUE spectra of low-redshift AGNs presented by Buson & Ulrich (1990). The Si II $\lambda 1263$ blend was measured in radio selected high-redshift quasars by Wilkes (1986). Using her tabulated values we find Si II $\lambda 1263/\text{Ly}\alpha=0.10\pm0.05$, as measured for 19 objects. This value is, however, significantly biased since there are 31 more objects in the same sample where Ly α was observed but Si II $\lambda 1263$ was too weak to be measured. The high-redshift Si II $\lambda 1263/\text{Ly}\alpha$ ratio is significantly larger than our low-redshift measurements, but in view of the strong bias present in the high-redshift measurements, we conclude that there is no well-established physical difference in the Si II $\lambda 1263$ emission between low and high-redshift quasars.

5.1.4 O I $\lambda 1304$ and C II $\lambda 1335$

We find O I $\lambda 1304/\text{Ly}\alpha=0.022\text{--}0.034$, and C II $\lambda 1335/\text{Ly}\alpha=0.004\text{--}0.038$, using the line fluxes given in Table 4. The O I $\lambda 1304$ and the C II $\lambda 1335$ lines are generally too weak to be measured in individual objects using the IUE. However, these two lines are detected in a composite IUE spectrum of 27 Seyfert 1 galaxies made by Véron-Cetty, Véron & Tarenghi (1983), from which we obtain ratios of O I $\lambda 1304/\text{Ly}\alpha=0.013$, and C II $\lambda 1335/\text{Ly}\alpha=0.0034$. Ground-based spectroscopy of high-redshift optically selected quasars gives O I $\lambda 1304/\text{Ly}\alpha=0.035\text{--}0.047$ and C II $\lambda 1335/\text{Ly}\alpha=0.025\text{--}0.028$, based on the composites of Francis *et al.* (who include N V with Ly α) and Boyle (1990). We therefore conclude that C II/Ly α and O I/Ly α ratios measured here are generally consistent with the ratios found in both low-redshift Seyfert 1 galaxies and high-redshift quasars.

5.1.5 Si IV $\lambda 1397$ +O IV] $\lambda 1402$

The Si IV +O IV] blend is detected in PKS 0405–123, H1821+643, and PG 0953+414; for the three objects Si IV +O IV] /Ly α =0.062, 0.068, and 0.086. The high-redshift quasars composite spectra of Francis *et al.* and Boyle (1990) give Si IV +O IV] /Ly α =0.19 and 0.10 respectively. There is no complete study available of the Si IV +O IV] blend in low-redshifts AGNs as it is rather weak for IUE observations. The only measurements we found are by Tinggui, Clavel & Wamsteker (1992) who analyzed IUE spectra of low-redshift AGNs which were selected to have strong Si IV +O IV] emission. Using their tabulated values for 11 objects we find Si IV +O IV] /Ly α = 0.18 ± 0.06 . Our values are, as expected, significantly smaller than the measurements of Tinggui *et al.*, and appear to be consistent with the ratio found by Boyle (1990) for high redshift quasars.

The Si IV $\lambda 1397$ and O IV] $\lambda 1402$ lines are strongly blended. We have attempted to make a direct deblending of the lines in PKS 0405–123 and PG 0953+414, where the template method could be applied (§4.2.5). Although our S/N are relatively high we could not make an accurate determination of the line ratios; we find, however, that a ratio of Si IV/O IV] $\sim 1 - 3$ is consistent with our data (Fig.7). Baldwin & Netzer (1978) have deblended Si IV and O IV] in 13 high-redshift quasars using a single template for each line and found that the blend is generally strongly dominated by O IV]. An alternative common technique to estimate the relative contributions of Si IV and O IV] is to use the mean wavelength of the blend. Using this approach Wills & Netzer (1979) found S IV/O IV] ~ 0.18 . However, in a recent analysis using the same methods, but with more detailed modeling of the expected mean wavelength, Tytler & Fan (1992) found Si IV/O IV] ~ 1 .

Both the Si IV and the O IV] multiplets have components with a rather large wavelength separation and different flux ratios; as a result the line profiles we constructed using the symmetric template are quite asymmetric. For example, a 1:1 Si IV/O IV] ratio results in a very asymmetric blend profile having a significantly stronger red wing (Fig.7). Deblending both lines using an identical symmetric template would lead in this case to a significant overestimate of the O IV] contribution. This might explain the significantly lower Si IV/O IV] ratio found by Baldwin & Netzer (1978), and implies that the Si IV/O IV] ratio found here might also characterize high-redshift quasars.

Our estimates of the Si IV/O IV] ratio were done assuming both lines are not systematically shifted from rest. If both lines are significantly blueshifted, then the implied Si IV/O IV] ratio would be lower. We cannot rule out a contribution of S IV $\lambda 1410$ of the order of 10%. This contribution will be larger if Si IV and O IV] are significantly blueshifted.

5.1.6 $C\text{ IV } \lambda 1549 + N\text{ IV] } \lambda 1486 + Si\text{ II } \lambda 1531$

Using the template deblendings we find a remarkably small dispersion in the $C\text{ IV}/Ly\alpha$ line ratios. Specifically, we find $C\text{ IV}/Ly\alpha=0.47, 0.48,$ and 0.46 for PKS 0405–123, PG 0953+414 and 3C273. We estimate that this ratio is 0.6 in H1821+643 (where we include only half the flux of the broad $C\text{ IV}$ component, as we assume the other half is due to the $\sim \lambda 1600$ feature). The $C\text{ IV}/Ly\alpha$ ratio has already been determined for a large number of AGNs. Using the measurements of Kinney *et al.* (1985, 1987), we find $C\text{ IV}/Ly\alpha=0.47\pm 0.16$ averaged over 14 AGNs with $z \sim 0.3 - 0.75$. This suggests that our small sample has emission line ratios which are typical of low to intermediate-redshift AGNs.

The $N\text{ IV] } \lambda 1486/Ly\alpha$ ratios we find are 0, 0.009, 0.008, and 0.025 for PKS 0405–123, H1821+643, PG 0953+414 and 3C273. The $N\text{ IV] } \lambda 1486$ line has not been previously measured in low-redshift AGNs. The high-redshift composite spectra of Boyle (1990) and Cristiani & Vio (1990) give $N\text{ IV]}/Ly\alpha=0.01-0.03$. The $N\text{ IV]}/Ly\alpha$ ratios found here are consistent with the range of average values found in high-redshift quasars.

We measured $Si\text{ II } \lambda 1531/Ly\alpha=0.038, 0,$ and 0.047 in PKS 0405–123, PG 0953+414 and 3C273, using the “symmetric $Ly\alpha$ ” template fitting. However, the $Si\text{ II } \lambda 1531$ doublet is very strongly blended with $C\text{ IV}$, and the measured values are based on the assumption that the intrinsic profile of $C\text{ IV}$ is identical to the profile of $Ly\alpha$. If $C\text{ IV}$ is intrinsically broader than $Ly\alpha$ by $\sim 10\%$, then the flux in $Si\text{ II } \lambda 1531$ will be consistent with zero for all objects. The $Si\text{ II } \lambda 1531$ doublet was previously measured by Ulrich *et al.* (1980) in 3C273 with a flux similar to the one found here. Four more detection in Seyfert galaxies are cited in Dumont & Mathez (1981), and no reports of this feature in high-redshift quasars were found in the literature.

5.1.7 $He\text{ II } \lambda 1640 + O\text{ III] } \lambda 1664$ and the $\sim \lambda 1600$ feature

We find $He\text{ II } \lambda 1640/C\text{ IV}=0.036, 0.021, 0.065, 0.022$ and 0.10 and $O\text{ III] } \lambda 1664/C\text{ IV}=0.073, 0.060, 0.032, 0.060, 0.061$ in PKS 0405–123, H1821+643, and PG 0953+414, 3C273, and Mrk 205. However, $He\text{ II}$ is blended with the unidentified $\sim 1600\text{ \AA}$ feature; this probably introduces a large and nonuniform systematic error in the measured $He\text{ II}$ flux. The $O\text{ III]}$ line is probably less affected by blending, as also suggested by the smaller dispersion in the $O\text{ III]}/C\text{ IV}$ ratios. We are not aware of any previous measurements of these lines in low-redshift AGNs (excluding 3C273). In high-redshift quasars, Boyle (1990) and Uomoto (1984) find $He\text{ II}/C\text{ IV}=0.12 - 0.13$ which is larger than our values, and $O\text{ III]}/C\text{ IV}=0.08 - 0.10$, which is consistent with the ratios found here for low-redshifts AGNs. The $He\text{ II}/C\text{ IV}$ measurements in high-redshift quasars are probably biased towards high values since they do not allow for blending with an underlying component, as done here. However, since $He\text{ II}$ cannot be reliably deblended, it is not clear a priori which of the $He\text{ II}/C\text{ IV}$ measurements is likely to be more realistic.

The unidentified broad emission feature at ~ 1600 Å was already noted in earlier studies, e.g. Wilkes (1984) and Boyle (1990). We did not use a separate Gaussian component to model this broad feature, since the three Gaussian components used to fit the C IV profile generally also allowed a satisfactory fit to this feature. The ~ 1600 Å feature mainly affected the parameters of the broad Gaussian component that describes the base of C IV, resulting in a shift of its center by $\sim 1700 - 8200$ km s $^{-1}$, and a very large FWHM $\sim 12,000 - 24,000$ km s $^{-1}$. The strength of the ~ 1600 Å feature varies considerably among the five objects in our sample. Characterizing the strength of the ~ 1600 Å feature by the ratio $F_{\lambda}^{\text{ob}}/F_{\lambda}^{\text{c}}$ (see §A.2) at $\lambda = 1610$ Å, we get a maximum value of 1.32 in H1821+643, and a minimum of 1.08 in Mrk 205.

The ~ 1600 feature is probably not an extended red wing of C IV because of the large velocity separation ($\sim 10,000$ km s $^{-1}$) from the peak of C IV. Wills, Netzer & Wills (1980) suggested that low level Fe II emission is present in the $\sim 1610 - 1680$ Å range.

5.1.8 N III] $\lambda 1750$ and Si II $\lambda 1814$

The N III] $\lambda 1750$ /C IV ratio found here is $0.0 - 0.016$ *vs.* 0.07 in higher redshift quasars (Boyle 1990; Uomoto 1984), while the Seyfert composite of Véron *et al.* (1983) gives N III]/C IV ~ 0.03 . The N III] line is very weak in our spectra and therefore has a large measurement error. Measurement uncertainties are not likely to be large enough to explain the factor of ~ 5 difference between our results and these for higher redshift quasars.

We find Si II $\lambda 1814$ /C IV = $0.0 - 0.01$, with about a factor of two possible error in this ratio due to the very low amplitude of the Si II $\lambda 1814$ triplet. We note, however, that some Fe II emission is possible at $1820 - 1840$ Å (see Wills *et al.* 1980); Fe II emission might strongly contaminate, or possibly dominate, the flux attributed here to Si II $\lambda 1814$. The Si II $\lambda 1814$ triplet was previously suggested in one Seyfert galaxy (private communication cited by Dumont & Mathez 1981). This feature has not been detected in high-redshift quasars.

5.1.9 Al III $\lambda 1857$ + Si III] $\lambda 1892$ + C III] $\lambda 1909$

The C III] $\lambda 1909$ line is strongly blended with the Si III] $\lambda 1892$ line, and somewhat blended with the Al III $\lambda 1857$ doublet. We find a ratio of Al III]/C III] = $0.05 - 0.33$ with a mean value of 0.16 , which is consistent with the ratios of 0.14 and 0.12 obtained for high-redshift quasars by Gaskell, Shields & Wampler (1981) and by Steidel & Sargent (1991). We note, however, that two Fe II multiplets are expected in the $1849 - 1868$ Å range (Wills *et al.* 1980), and these might dominate the flux we attribute to the Al III doublet. Both Si III] $\lambda 1892$ and Al III $\lambda 1857$ have not been previously detected in the spectra of low-redshift AGNs (except 3C273).

We measure Si III]/C III] = $0.03 - 0.35$ with a mean value of 0.15 , which is roughly consistent with the value of 0.22 obtained by Gaskell *et al.* for high redshift quasars. However, Steidel &

Sargent find the Si III] contribution to be consistent with zero in $\sim 90\%$ of their 92 objects. It is not clear why the large and heterogeneous sample of Steidel & Sargent differs from our sample and from the sample of Gaskell *et al.*

5.2 Earlier observations of our five AGNs

All five AGNs described in this paper were previously observed with the IUE. The observations of PKS 0405–123 and PG 0953+414 are described in Green *et al.* (1980). A detailed analysis of the observations of 3C273 is described in Ulrich *et al.* (1980). Measurements of UV lines in Mrk 205 are given by Buson & Ulrich (1990), and the observations of H1821+643 are described in Kolman *et al.* (1991).

A number of the emission lines measured here were not measured or detected in the IUE spectra of our five AGNs. In particular, most lines that are weaker than the Si IV+O IV] blend could not be reliably measured in the IUE spectra. A comparison of the line fluxes measured with both the HST and the IUE indicates differences ranging from $\sim 10\%$ to about a factor of two. A partial explanation for the differences is intrinsic variability of the emission line fluxes during the typically 5-10 year interval between the IUE and the HST observations. In some lines the different fluxes are probably also related to the different wavelengths at which the continuum windows are set. For example, in C IV we use a continuum window at 1720 \AA , while previous studies usually employed a window at $\sim 1600 \text{ \AA}$, which can be strongly affected by the unidentified $\sim 1600 \text{ \AA}$ feature (see §5.1.7). In the case of weaker lines, such as the Si IV+O IV] blend, it is likely that some of the difference results from the relatively low S/N of the IUE measurements. In the case of 3C273, there are two very weak lines, Si II $\lambda 1194$, and [Ne V] $\lambda 1575$, which Ulrich *et al.* (1980) identified in the IUE spectra, but which we do not detect in our HST spectra. The significantly higher S/N and spectral resolution of the HST data allows us to place an upper limit on the flux in these lines which is about three times lower than the flux measured by Ulrich *et al.* (1980). We confirm the Ulrich *et al.* detection in 3C273 of the Si II $\lambda 1263$ multiplet, and we possibly also detect the Si II $\lambda 1531$ multiplet (see below), although the fluxes we measure for the two Si II lines differ by $\sim 50\%$ from the IUE values.

6 PHYSICAL IMPLICATIONS OF THE LINE PROFILES

6.1 The Number of Clouds in the Broad-Line-Region

If the profiles of the line emitted by each individual cloud in the broad-line-region (BLR) is unresolved (i.e. narrower than about 230 km s^{-1}), and the number of individual clouds contributing to the integrated line flux is significantly smaller than the number of observed photons, then the

fluctuations in the number of clouds contributing to each spectral resolution element will result in a statistically significant structure in the observed line profile. Our fits to the line profiles (Figs. 3a-e) are generally characterized by $\chi_r^2 \sim 1 - 2$. Given the high S/N of our spectra, this low χ^2 implies a remarkable lack of small scale structure in the line profiles over that predicted from the finite number of photons observed. Using the strongest UV lines, we find that the number of clouds is typically larger than a few times 10^4 . This argument gives a rough lower limit on the number of clouds, since some of the apparent deviations from the smooth model fit could be due to uncalibrated low level structure in the detector response, or weak absorption lines. A similar lower limit on the number of clouds was obtained by Capriotti, Foltz & Byard (1981) and by Atwood, Baldwin & Carswell (1982) based on the smoothness of the H α and H β profile.

The limit obtained above depends on the width of the line emitted by each individual cloud. Significant broadening, for example by electron scattering (see Shields & McKee 1981; Emmering, Blandford & Shlosman 1992), can reduce by an arbitrary amount the lower limit on the number of clouds in the BLR.

6.2 Line Velocity Shifts

As first noticed by Gaskell (1982), different emission lines yield systematically different values for the redshift. A recent detailed analysis of systematic velocity shifts is presented by Tytler & Fan (1992).

We find (see Tables 5 and 7) that the peaks of Ly α , C IV, and C III] are typically blueshifted by 150 km s $^{-1}$ to 250 km s $^{-1}$ (relative to [O III] λ 5007), while the low ionization lines Mg II, and H β , are in most cases only marginally shifted to the red. For He II λ 1640 we find the largest average blueshift, -476 ± 98 km s $^{-1}$ (excluding 3C273 with a shift of -983 km s $^{-1}$) with respect to [O III] λ 5007, or -507 km s $^{-1}$ with respect to H β . (The possible systematic error is about 60 km s $^{-1}$, see §4.2.3).

The template fits for O VI (using the statistical-weights multiplets ratios) are consistent with a zero velocity shift (Table 7), although the Gaussian decomposition (Table 5) appeared to suggest large shifts. This is partly caused by the relatively low S/N of the O VI profile. Another source for a large systematic error in the shift concerns the estimate of the mean wavelength of the O VI doublet. The value used for the Gaussian decomposition is 1033.816 Å (Morton 1991), which is the statistical-weight mean of the two doublet components. However, due to the large velocity separation of the doublet components (1651 km s $^{-1}$), the observed peak is dominated by the stronger component which is at -548 km s $^{-1}$ relative to the mean wavelength. Thus, as clearly seen in Fig.6, the peak of the fitted O VI profile appears to be blueshifted, even though the fit was made using O VI at rest. The shift in the position of the peak depends on the amount of blending of the doublet components, i.e. the ratio of the template width to the doublet velocity

separation. Another important source for a systematic error in measuring velocity shifts is the ratio of fluxes in the multiplet components. The weighted mean multiplet wavelengths used here are appropriate for the case of absorption. In the case of emission, the ratio of fluxes in a multiplet can deviate from the ratio of statistical weights (e.g. Netzer & Wills 1983). If all components are optically thick, thermalized, and the emitting gas is isothermal, then the flux ratio is practically one. As shown in Table 7, template deblending with a flux ratio of one implies higher blueshifts, in particular for O VI where the velocity separation of the doublet is largest.

The relatively small velocity shifts found here for O VI, Ly α , C IV, and C III], are consistent with the results of Tytler & Fan, which are based on ground-based spectra of high-redshift quasars. Our results differ from those obtained in earlier analysis of high-redshift quasars where larger velocity shifts were found (e.g. Corbin 1990).

Tytler & Fan find a He II velocity shift of -454 km s^{-1} using the Balmer lines, rather than [O III], to determine rest frame redshift. This value is very similar to the -507 km s^{-1} average shift found here. For O I $\lambda 1303$, we measure an average shift of $261 \pm 129 \text{ km s}^{-1}$ relative to H β , while Tytler & Fan find -50 km s^{-1} . One trivial source for the difference is the fact that we use O I rest wavelength of 1303.49 \AA (Morton 1991), *vs.* 1304.46 \AA used by Tytler & Fan. Using the Tytler & Fan value for the rest wavelength reduces our shift to $88 \pm 129 \text{ km s}^{-1}$, which is consistent with their result. Another complicating effect in the case of O I is the possible contribution of Si II $\lambda 1308$ (Fig.2b). Blending with Si II $\lambda 1308$ could result in the apparent redshift of the O I line found here and in earlier studies of high redshift quasars (e.g. Wilkes 1984).

We find that the other UV lines are generally either too weak or too blended for a reliable determination of the position of their peak.

6.3 A Comparison of the Line Profiles

As shown in Fig.5, in all four quasars Ly α has a narrower peak than C IV, but similar broad wings (average FWHM= 3514 km s^{-1} for C IV *vs.* 3014 km s^{-1} for Ly α). A similar effect was noted by Wilkes (1984) in high-redshift quasars, and by Buson & Ulrich (1990) in low-redshift AGNs. Some of this difference results from the fact that C IV is a doublet with a velocity separation of 499 km s^{-1} , and, as shown in Fig.6, one can get a reasonable fit to C IV using the Ly α template. However, the fit in Fig.6 assumes some contribution from the Si II $\lambda 1531$ doublet, and the agreement is not good in the red wing of C IV beyond $\sim 1000 \text{ km s}^{-1}$, possibly due to blending with the $\sim 1600\lambda$ feature. Given these possible blending effects we cannot reliably determine the reality of the apparent small differences between the Ly α and C IV profiles (see Fig.5).

The C III] line generally has the narrowest peak of the broad lines, despite the fact it is blended with Si III] and Al III (and possibly also Fe II). The relative intensity of C III] is suppressed at

densities above a few times 10^9 cm^{-3} . The narrow peak of C III] therefore suggests that the low velocity gas, possibly at larger distances, has a lower density and is a more efficient emitter of C III] than the high velocity gas.

Detailed theoretical predictions of the relative line profiles were made by Rees, Netzer & Ferland (1989), who calculated the line emission for various spherically symmetric distributions of mass-conserving clouds and various scalings of the ionization parameter U ($=$ density of ionizing photons/gas density), with radius. The motion of the clouds was assumed to be virialized, i.e. line width $\propto R^{-1/2}$, where R is the distance of the cloud from the central continuum source. Our results rule out their model with $U \propto R^{-1}$, as it predicts differences in the line profiles which are significantly larger than observed here. Our results are consistent with the Rees *et al.* model with $U = \text{constant}$, which predicts only small differences in the line profiles and that C III] should be narrowest. The Rees *et al.* model with $U \propto R^{-1/2}$ predicts larger differences, but it cannot be clearly ruled out by our data.

Fig.5 shows that the O VI blend is significantly broader than all other strong emission lines (average FWHM= 5148 km s^{-1} , *vs.* 3014 km s^{-1} for Ly α , see §4.2.3). However, the template fitting (Fig.6) indicates that despite this large apparent difference the O VI blend can be well fit (excluding the red wing at $v > 2000 \text{ km s}^{-1}$) with a sum of symmetric Ly α components, and the larger apparent width of the O VI blend can be all attributed to the large velocity separation of the O VI doublet (1651 km s^{-1}) and the additional blending with Ly β (at -2348 km s^{-1}). The width of the O VI blend, relative to the width of its individual components, depends on the ratio of the individual component width to the velocity separation of the doublet. This broadening effect will be largest in objects with the narrowest lines, and we generally expect O VI will have a systematically larger width than all other lines. The claim made by Osmer & Smith (1976) that the widths of O VI and Ly α in high-redshift quasars are comparable must be due to the combination of intervening absorption systems and low S/N spectra.

As shown in Fig.6, the red wing of O VI ($v > 2000 \text{ km s}^{-1}$) is not well fit by the Ly α template. The excess flux in the observed broad red wing is $\sim 20-40\%$ of the flux fit with the Ly α template. If the observed line width is due to bulk velocity of the emitting gas, then it implies that the high velocity gas produces emission with a significantly higher O VI/Ly α ratio than the low velocity gas. According to the ‘standard’ BLR photoionization models (e.g. Kwan & Krolik 1981; Rees, Netzer & Ferland 1989) the relative flux in O VI increases with increasing ionization parameter. In particular, Ferland *et al.* (1992) find that O VI becomes the strongest line once the ionization parameter U is larger than 0.5 (assuming a gas density $n = 10^{10} - 10^{11} \text{ cm}^{-3}$). This suggests that the high velocity gas responsible for the red wing of O VI is subject to a high ionization parameter. If the gas velocity is determined by the depth of the potential well, then this implies the presence of clouds with U significantly larger than 1 at small distances from the ionizing continuum source.

There are a number of Fe II multiplets between O VI and Ly α . No reliable prediction of their strength is available. It is possible that the apparent excess flux in the wing of O VI discussed above is mostly due to Fe II emission.

The peak of the low ionization H β line is systematically redshifted with respect to the other prominent UV lines. It also appears to have a distinctly asymmetric shape in two of our objects, where the red wing shows excess emission. Some of this excess might be due to residual Fe II emission, since, as noted by Boroson & Green, the fixed Fe II template used here (based on I Zw 1) is not a good representation of the Fe II emission in some objects. However, residual Fe II is not likely to be responsible for the strong line asymmetry in H1821+643, since all other lines in this object display the same characteristic asymmetry.

The clearest difference between the low and high ionization lines is that the later are typically blueshifted ($\sim 150 - 250 \text{ km s}^{-1}$, and $\sim 500 \text{ km s}^{-1}$ for He II $\lambda 1640$) relative to the low ionization lines. The model suggested by Collin-Souffrin *et al.* (1988, see also Dumont & Collin-Souffrin 1990, and references therein), invokes separate populations of high and low column density clouds having different spatial configurations, and presumably different kinematics, which are subject to different ionizing continua. It is not clear whether the overall similarity of the low and high ionization line profiles is consistent with such a model.

6.4 Symmetry of the Line Profiles

6.4.1 Measured Limits on the Asymmetry

The observed Ly α blend is highly symmetric in PG 0953+414, and 3C273 (see Fig.4). We find $\left| F_{\lambda(v)}/F_{\lambda(-v)} - 1 \right| \leq 0.04$ for $0 \leq v \leq 2000 \text{ km s}^{-1}$, where v is the velocity shift (positive for redshift) from the peak of the best-fit model to the observed line profile, and $F_{\lambda(v)}$ is the flux of the best-fit model. The template fitting of Ly α +N V (Fig.6) indicates that no intrinsic asymmetry of Ly α is required even at velocities significantly above 2000 km s^{-1} . In three of the four quasars, PKS 0405–123, PG 0953+414, and 3C273, practically all of the observed red-excess of Ly α can be attributed to blending with a N V doublet whose two components have the same symmetric profile assumed for Ly α (the “symmetric Ly α ” template). The high degree of symmetry of Ly α in a significant fraction of AGNs was noted previously by many authors. In particular, in low-redshift AGNs by Buson & Ulrich (1990), in intermediate redshift AGNs by Kinney *et al.* (1987), and in high-redshift AGNs by Wilkes & Carswell (1982), but no quantitative limit was put on the possible asymmetry of Ly α in these studies.

Ly α is predicted to be blended with the semi-forbidden O V] $\lambda 1218$ (see Baldwin & Netzer 1978). This line can be used as a tracer of gas with a high density and ionization parameter. In particular, Ferland *et al.* (1992) predict O V]/Ly α > 0.1 for $U > 0.1$ and $n = 10^{11} \text{ cm}^{-3}$. Given

the assumption that $\text{Ly}\alpha$ is intrinsically symmetric we can rule out an $\text{O V}]/\text{Ly}\alpha$ ratio larger than 3-10%.

The observed C IV profile also has a very symmetric core, with $|F_{\lambda(v)}/F_{\lambda(-v)} - 1| \leq 0.05$ for $0 \leq v \leq 2000 \text{ km s}^{-1}$, in PKS 0405–123, PG 0953+414, and 3C273. The observed red excess asymmetry in C IV might be related to blending with the $\lambda \sim 1600 \text{ \AA}$ feature. Buson & Ulrich (1990) found C IV to be very symmetric in IUE spectra of low-redshift AGNs. However, Young *et al.* (1982), Wilkes (1984, see detailed profiles in Kallman *et al.* 1993), and Ulrich (1989) generally find a blue, rather than red, excess asymmetry in C IV in high-redshift quasars. Some of the difference might result from their use of a $\sim 1600 \text{ \AA}$ continuum window, rather than the $\sim 1700 \text{ \AA}$ window (used here) which generally has a lower flux, and therefore implies more flux in the red wing of C IV.

The symmetry of C III] could not be addressed reliably due to the strong blending with the Si III] line.

6.4.2 Constraints on the Models

The very high degree of symmetry of $\text{Ly}\alpha$ presents a strong constraint on models for the cloud dynamics in the BLR. $\text{Ly}\alpha$, and possibly also C IV for high values of U , are expected to be emitted highly anisotropically from each of the broad line clouds (Ferland, Netzer & Shields 1979, Ferland *et al.* 1992). Thus models invoking a pure radial cloud velocity field will produce a strong line asymmetry, and such models are ruled out. A similar conclusion was recently reached by Kallman *et al.* (1993), based on a comparison of the observed prominent line profiles with predictions of models which combine cloud kinematics and photoionization calculations. Some of this asymmetry might be lowered by preferential obscuration of part of the BLR, or by electron scattering of the ionizing continuum (Kallman & Krolik 1986; see also some examples in Netzer 1990). It seems unlikely that the combination of these effects will balance the line asymmetry to the low level measured here. A radial velocity field for the clouds in the BLR has also been ruled out in a few AGNs based on the response of the emission line profiles to continuum variations (e.g. Maoz *et al.* 1991; Koratkar & Gaskell 1991). Models involving an isotropic cloud velocity distribution at each distance produce more symmetric profiles (note that, as shown in Fig.4, special relativistic effects still produce a noticeable asymmetry even in this case), but these models also imply that all the clouds in the BLR collide with each other within a few dynamical time scales, i.e. a few dozens of years. Alternatively, the observed line width might not be related to bulk motion but rather reflect broadening produced by optically thick inelastic electron scattering. This requires a rather high column density of obscuring warm gas in the BLR (cf. Shields & McKee 1981; Emmering, Blandford & Shlosman 1992).

6.5 Narrow Line Contribution

We find that the C III] line has the highest average narrow-[O III]-like line component, followed by Ly α , with O VI having the smallest narrow line contribution. The contribution of the narrow component does not appear to be related to the objects' luminosity in our small sample. The rather low narrow line contribution to Mg II found here was previously noted in high-redshift quasars by Grandi & Phillips (1979). However, the peaks of Mg II, C IV, and in particular O IV, are broadened as they are unresolved doublets (velocity-equivalent separations are respectively 770, 500, and 1650 km s⁻¹), and therefore the maximum contribution of the narrow component to these doublet cannot be reliably measured without more detailed modeling.

The maximum narrow-line-like component of the broad permitted lines was recently studied in detail by Wills *et al.* (1993) in a sample of 7 radio-loud quasars. They found that the upper limits on the narrow-line contributions to the prominent UV lines are significantly smaller than the upper limit in H β . However, we find the upper limit on the narrow line contribution in H β is comparable, or smaller, than the upper limit for the UV lines (Table 6). Boroson & Green (1992) have noted that the maximum possible narrow component in H β is rarely more than 3%, which is consistent with the values found here for H β .

The small contribution of the narrow lines to the broad line profiles appears to imply a correspondingly small covering factor of the NLR relative to the BLR, and a low ionization parameter. We note, however, that this is not necessarily true if dust is embedded with the ionized gas in the NLR, as recently shown by Netzer & Laor (1993).

7 PHYSICAL IMPLICATIONS OF THE OBSERVED LINE RATIOS

The emission line spectra of quasars in the wavelength range $912 \text{ \AA} < \lambda < 1216 \text{ \AA}$ was first predicted by Bahcall & Sargent (1967), based on expected correlations between the intensities of lines in the near UV and far UV. Of the 13 ions originally suggested by Bahcall & Sargent, we have detected the following four: O VI, C III, N III, and S VI. Bahcall & Sargent predicted C III $\lambda 977$ would be the strongest emission line in the $912 \text{ \AA} < \lambda < 1216 \text{ \AA}$ range, followed by Ly β , Ly γ and O VI $\lambda 1034$. As mentioned above, we find the O VI flux to be about an order of magnitude larger than the flux in either C III, Ly β or Ly γ . The other 9 ions, which were not detected here, were predicted by Bahcall & Sargent to produce weak, or very weak, lines.

Our understanding of various physical processes responsible for line emission in AGNs has evolved considerably in the 26 years since the original work of Bahcall & Sargent (1967). The most recent photoionization models are described by Ferland & Persson (1989), Rees, Netzer & Ferland (1989), Netzer (1990), and Ferland *et al.* (1992). Our discussion below is based on the results presented in these papers. The line ratios predicted by these models depend on the density

(n), ionization parameter (U , defined in §6.3), and column density of the clouds in the BLR (all these models assume gas with a solar metallicity and use a slab geometry). We do not attempt to use our measurements to make a detailed analysis of the physical conditions in the BLR, but rather point out the major implications of our emission line measurements.

The Ly β line was first predicted to be observable in quasars by Bahcall (1966). More recent calculations of the Ly β /Ly α ratio, based on the “standard” BLR models, are presented by Kwan (1984). As discussed in §5.1.2, we find in our four quasars Ly β /Ly α =0.03–0.12. According to Kwan (1984), the Ly β /Ly α ratio is determined by the value of $U \times n$, i.e. by L_{ionizing}/R^2 , where L_{ionizing} is the ionizing luminosity of the quasar, and R is the distance of the cloud from the ionizing continuum source. Below we estimate L_{ionizing} for our objects, and use it to get a direct estimate of the size of the BLR. L_{ionizing} is estimated assuming the “standard” AGN ionizing continuum shape given in Laor & Draine (1993, Fig.7), which we scale by the observed luminosity λL_{λ} at $\lambda = 1150\text{\AA}$. Assuming $H_0=50 \text{ km s}^{-1}$ and $q_0 = 0$, we get $\lambda L_{\lambda} = (7.9, 2.8, 0.60 \text{ and } 4.1) \times 10^{46} \text{ erg s}^{-1}$, for PKS 0405–123, H1821+643, PG 0953+414 and 3C273. These values imply a total ionizing photon flux of $(2.9, 1.1, 0.22 \text{ and } 1.7) \times 10^{57} \text{ photons s}^{-1}$. Using the plot of Ly β /Ly α as a function of $n \times U$ in Fig.4 of Kwan (1984) and the ionizing photon flux, we get $R=2.3, 1.2, 0.46 \text{ and } 0.47 \text{ pc}$. These values are somewhat larger than expected from an extrapolation of the $R=0.1(L/10^{46} \text{ erg s}^{-1})^{1/2} \text{ pc}$ relation suggested at lower luminosities (e.g. Netzer 1990, Peterson 1993). However, the Ly β /Ly α calculations of Kwan were carried out for $U = 0.01 - 0.06$, which is significantly below the values suggested by O VI and C III (see below). Kwan also assumed a somewhat different ionizing continuum shape than Laor & Draine. It remains to be tested whether the Ly β /Ly α ratio can be used as a useful absolute distance indicator for higher values of U .

The Ly γ line was deblended from C III $\lambda 977$ in PKS 0405–123, and we find Ly γ /Ly β = ~ 0.5 . This ratio is consistent with the Ly γ /Ly β = ~ 0.35 prediction of Bahcall (1966) for optically thin gas, with an additional contribution, having a similar line ratio, due to escape from larger optical depths (see Kwan 1984).

The C III $\lambda 977$ line was measured for PKS 0405–123 and H1821+643. The C III/O VI ratio for these two objects are 0.23 and 0.09. The predicted C III/O VI ratio is close to one for $U = 0.1$, and it decreases to ~ 0.3 for $U = 1$. Thus the C III $\lambda 977$ /O VI ratio measured here suggests a $U \sim 1$ component in the BLR, if both lines originate from the same cloud distribution. The C III $\lambda 977$ /C III] $\lambda 1909$ ratio is a good indicator of the gas density, and is likely to be very weakly dependent on the gas composition and column density. We measured C III/C III]=0.46 and 0.17 for PKS 0405–123 and H1821+643. These ratios imply $n \sim 3 \times 10^9 - 2 \times 10^{10} \text{ cm}^{-3}$, if both lines come from the same distribution of clouds. These values of n are within the range suggested by the “standard” photoionization models. At higher densities the C III/C III] ratio increases since C III] is collisionally suppressed; for example, at $n = 10^{11} \text{ cm}^{-3}$ we get C III/C III]> 1, which is

significantly higher than found here. We note that the C III $\lambda 977$ profile is too noisy to determine whether it originates from the same distribution of clouds as the C III] $\lambda 1909$ line.

The N V $\lambda 1240/\text{Ly}\alpha$ ratio in our sample is more than a factor of two smaller than found in high-redshift quasars and it displays a very small scatter, 0.135 ± 0.01 (see §5.1.3). The N V/Ly α ratio generally increases with U and n , however; even for $n \simeq 10^{10} \text{ cm}^{-3}$ and $U \simeq 1$ it is still only ~ 0.05 . As mentioned in §6.4, the N V profile is fit very well with a symmetric Ly α profiles, which suggests that Ly α and N V come from distributions of clouds having similar U and n . (Unless U and n are uncorrelated with velocity). A possible explanation for the high N V/Ly α ratio is a higher than solar nitrogen abundance and an overall higher than solar metallicity, as recently suggested by Hamman & Ferland (1992). The large systematic errors that are possible in the measurement of the N V/Ly α ratio in low S/N data, and in particular in high-redshift quasars (see §5.1.3), might affect some of the conclusions of Hamman & Ferland (1992) concerning the amount of chemical evolution in quasars.

Earlier studies of high-redshift quasars have noted that the observed O VI $\lambda 1034/\text{Ly}\alpha$ ratio requires an optically thin BLR component having a large U and a covering factor close to unity (e.g. Baldwin & Netzer 1978). As mentioned above (§5.1.2) we measured an average O VI $\lambda 1034 + \text{Ly}\beta/\text{Ly}\alpha + \text{N V}$ ratio that is about twice the average ratio found in high-redshift quasars. Our deblended average ratio is O VI $\lambda 1034/\text{Ly}\alpha = 0.32 \pm 0.10$ when all the O VI flux is included, and 0.25 ± 0.09 when we include only the fraction of O VI which is fit with the symmetric Ly α profile. These high O VI/Ly α ratios imply a BLR cloud component with $U \gtrsim 0.5$ (for $n \sim 10^{10} - 10^{11} \text{ cm}^{-3}$), which emit the bulk of the O VI emission. It is also possible that there is an inner higher velocity component of the BLR, with a higher U , which produces the excess flux in the wing of O IV (see §6.3). This component has to be optically thin below the Lyman limit, so it does not produce a significant Ly α emission. Ferland, Korista & Peterson (1990) and Peterson *et al.* (1993) invoked an optically-thin component to explain non-variable broad wings of Ly α in a variable Seyfert 1 galaxy. Another possible interpretation for the excess flux in the wing of O VI is blendings of other ions, such as Fe II (§6.3).

The He II $\lambda 1640/\text{He II } \lambda 4686$ ratio is considered to be a good reddening indicator since it is relatively insensitive to the BLR model parameters. The predicted value for this ratio is in the 8 – 11 range, and we measure values of 21.3, 19.6, 12.4, and 7.3 for PKS 0405–123, H1821+643, PG 0953+414, and 3C273, respectively. However, the optical and UV spectra were not obtained simultaneously, and both He II $\lambda 1640$ and He II $\lambda 4686$ are strongly blended with other emission components. The blending of He II $\lambda 4686$ with the optical Fe II emission was corrected using the Boroson & Green method. This procedure requires a high S/N emission line template (based on the spectrum of a narrow line quasar), and it cannot yet be applied for correcting the measurements of He II $\lambda 1640$. The He II $\lambda 1640/\text{He II } \lambda 4686$ ratios measured here could therefore include a significant systematic error.

The Si IV $\lambda 1397$ /O IV] $\lambda 1402$ ratio is predicted to be in the $\sim 1-10$ range. Earlier observations of high-redshift quasars appeared to indicate Si IV/O IV] significantly smaller than one, but more recent analysis, based on the mean position of the blends peak indicated Si IV/O IV] ~ 1 . As described above (§5.1.5, and Fig.7), we find using template fitting that Si IV/O IV] $\sim 1-3$ is consistent with our data for PKS 0405–123 and PG 0953+414, and can therefore be explained by “standard” BLR models.

The presence of semi-forbidden lines in our spectra, N IV] $\lambda 1486$, O III] $\lambda 1664$, N III] $\lambda 1750$, Si III] $\lambda 1892$, and C III] $\lambda 1909$, indicates BLR components with densities below 10^{10} to 10^{11} cm^{-3} . These lines, together with other prominent lines, have been pointed out as useful chemical abundance indicators (e.g. Shields 1976; Uomoto 1984). However, analysis of the chemical abundances requires detailed modeling of the BLR, which is beyond the scope of this paper.

8 SUMMARY

We have analyzed the UV emission-line properties of five low-redshift AGNs using high-resolution and high-signal-to-noise observations and an objective algorithmic procedure for modeling and deblending the line profiles. The major results are the following.

1. We measure a flux ratio $\text{Ly}\beta/\text{Ly}\alpha = 0.03-0.12$ for the four quasars. Values in this range were first predicted for quasars using photoionization theory more than a quarter of a century ago (Bahcall 1966), but previous measurements have been limited by the sensitivity and resolution of the available UV spectra. The $\text{Ly}\beta/\text{Ly}\alpha$ ratios can be used—together with an estimate of the ionizing luminosity of each object—to calculate directly the size of the BLR.
2. The cores of the $\text{Ly}\alpha$ and C IV blends are symmetric in two and three objects respectively. We find flux ratios, $\text{Flux}(\text{red wing})/\text{Flux}(\text{blue wing})$, that deviate from unity by less than 2.5% within 2000 km s^{-1} of the line peaks. The $\text{Ly}\alpha + \text{N V}$ blend can be fit well using the “symmetric $\text{Ly}\alpha$ ” template for both lines. This result indicates that practically all of the apparent $\text{Ly}\alpha$ asymmetry at large velocities from the $\text{Ly}\alpha$ line core is due to blending with N V. The high degree of symmetry of $\text{Ly}\alpha$ argues against models in which the velocity field in the BLR has a significant radial component.
3. The observed smoothness of the $\text{Ly}\alpha$ and C IV line profiles requires that at least $\sim 10^4$ individual clouds contribute to the broad line emission if bulk velocity is the only line broadening mechanism. Electron scattering (e.g. Shields & McKee 1981; Emmering *et al.* 1992) could explain the smoothness with significantly fewer clouds.
4. The overall similarity of the $\text{Ly}\alpha$ and the C IV line profiles rules out models of the BLR

having a distribution of mass-conserving virialized clouds with $U \propto R^{-1}$. Models in which $U = \text{constant}$ are consistent with the similarity of the Ly α and C IV profiles.

5. We make the first relatively accurate measurement of C III $\lambda 977$ in quasars. We find C III $\lambda 977$ /C III] $\lambda 1909 \simeq 0.46$ in PKS 0405–123 and 0.17 in H1821+642. These ratios imply an electron number density $n_e \sim 3 \times 10^9 - 2 \times 10^{10} \text{ cm}^{-3}$, which is consistent with “standard” photoionization models (e.g. Rees *et al.* 1989).
6. An estimate of the Ly γ /Ly β ratio is possible in PKS 0405–123. We find Ly γ /Ly $\beta \sim 0.5$, which is consistent with the prediction for optically thin gas (Bahcall 1966), with an additional contribution, having a similar line ratio, due to escape from larger optical depths (Kwan 1984).
7. The average deblended O VI/Ly α ratio is 0.25–0.32. This ratio and the rather low value found for the C III $\lambda 977$ /O VI line ratio implies a BLR component with an ionization parameter $U \gtrsim 0.5$.
8. The maximum contribution of a narrow ([O III]-like) component to the observed O VI, Ly α , C IV, C III] and H β line profiles is about 3 – 6% of the total line flux. The narrow-line contribution is largest in C III]. The small narrow-line contribution implies either that the covering factor of the narrow-line region is small or that dust is important (see Laor & Draine 1993).
9. An unresolved component having a FWHM $< 230 \text{ km s}^{-1}$ typically contributes less than 0.5% of the observed broad-line flux.
10. The mean N V/Ly α ratio for the four quasars is 0.135 ± 0.01 . This high value for the N V/Ly α ratio may result from a higher-than-solar N abundance and metallicity (Hamann & Ferland 1992).
11. Template fitting of the Si IV/O IV] $\lambda 1400$ blend, including all the individual multiplet components, indicates Si IV/O IV]=1–3, which is close to the values predicted theoretically (e.g. Rees *et al.* 1989). Previous observational estimates in high-redshift quasars yielded significantly lower values for this ratio (e.g. Baldwin & Netzer 1978), which could have been affected by the intrinsic asymmetry of the Si IV and the O IV] multiplets.
12. A comparison of some of the prominent line profiles suggests a dependence of U and n on velocity. In particular, the excess flux in the red wing of O VI, relative to a fit with the template Ly α profile, suggests the presence of high-velocity optically-thin gas, with U significantly larger than 1, which could be located closer to the continuum source than most of the BLR. The significantly narrower peak of C III] $\lambda 1909$, compared with the peaks of all

other prominent emission lines, suggests a lower density for the lower-velocity gas, which could be located outside most of the BLR.

13. We measure for the first time in the spectra of individual quasars the S VI $\lambda\lambda 933,945$ doublet and the N III $\lambda 991$ emission line.
14. The peaks of the Ly α , C IV, and C III] emission lines are typically blueshifted by 150 km s^{-1} to 250 km s^{-1} relative to [O III] $\lambda 5007$, while He II $\lambda 1640$ displays a significantly larger blueshift of about 500 km s^{-1} . The low ionization lines of Mg II, H β , and O I $\lambda 1304$ are in most cases only marginally shifted to the red. These results are generally similar to what has been found at large redshifts (cf. Tytler & Fan 1992).

Emission features are omnipresent in the UV. We have been unable to find a wavelength range that shows unambiguously an underlying featureless continuum. Broad quasi-continuum features at a level of $\sim 10\%$ are evident at most wavelengths. These emission features can produce systematic errors, resulting in an overestimate of the true continuum level and possibly an underestimate of the emission-line flux. Another consequence of the high density of UV emission lines is that essentially all of the UV lines are blended to some degree. There is, for example, an unidentified, broad, and in some cases strong, emission feature at $\lambda \sim 1600 \text{ \AA}$. A similar feature has been detected in the spectra of high-redshift quasars (see e.g. Boyle 1990). A practical way to identify the various weak and blended emission features is by studying narrow-line quasars, where confusion due to blending is minimized (e.g. Baldwin *et al.* 1988). Spectra of narrow-line quasars can then be used as templates for the study of normal quasars, as done by Boroson & Green (1992) in the optical regime.

The HST observations presented here provide new information on the fluxes and profiles of many lines emitted by different ion species. These quantitative data (and similar data from other HST observations of quasars), when combined with detailed photoionization models, will lead to improvements in our understanding of the physical conditions, the chemical abundances, and the dynamics of the gas in the central regions of active galaxies.

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APPENDIX

THE LINE AND CONTINUUM FITTING ALGORITHM

Below we describe in details the method we used to model the continuum and the line shapes. The advantages of this method are that it is objective, well defined, and it produces a good fit to the observed profiles. This method is especially useful for generating an acceptable smooth model for the “true” emission line profiles, as it allows narrow absorption features to be identified and rejected in the fitting process. The main disadvantage of this method is that when fitting strongly blended lines (e.g. N V), the individual component parameters are not a unique solution, and other solutions might be more realistic. This disadvantage can be overcome in some cases by using a template emission line profile to deblend strongly blended lines, as further discussed in §A.4.

A.1. *The Continuum Fit*

To measure lines fluxes, one first needs to define the continuum shape and level. It is conventional and convenient for many purposes to describe the continuum of AGNs as having a power-law shape, i.e. $d \ln F_\lambda / d \ln \lambda = \text{constant}$. There is, however, no appreciable wavelength range in our spectra which clearly shows such a power-law continuum uncontaminated with line emission. Weak emission features, with widths of $\sim 10 - 100 \text{ \AA}$, are present at a level of a few percent of the continuum level in many parts of the spectrum. There are also indications of broader quasi-continuum features of a larger amplitude. These broader features are suggested by the fact that a low order polynomial that is fit to the observed continuum at a few wavelengths generally passes significantly below (by $\sim 10\%$ or more) the apparent continuum level at intermediate wavelengths where no clear emission features are observed (see also Francis et al. 1991). These broad features could be due to low level emission by various blends, in particular Fe II, as observed in the $\sim 2000 - 4000 \text{ \AA}$ range (Wills, Netzer & Wills 1985). In order to avoid these quasi-continuum features as much as possible, we divide each spectrum into sections that are about $\sim 200 \text{ \AA}$ wide (note that rest-wavelengths are used throughout the Appendix), and for each section define the local continuum as a power-law that intersects the spectrum at the two end points. The flux at each of the two end points is defined as the median flux value in an interval which is 21 pixels (~ 5 resolution elements) wide, which corresponds to a wavelength extent $\Delta \lambda \sim \lambda/250$. The position of these end-point continuum windows are selected subjectively, under the guiding principle that they reside in broad local flux minima. The wavelengths selected for the continuum windows for each object are given in Table 3.

A.2. The Line-Fitting

We fit each line blend with a set of Gaussian components. We use three Gaussian components, i.e. a total of 9 free parameters, to fit each of the prominent UV lines, Ly α , C IV λ 1549, and C III] λ 1909, two to three components for O VI λ 1034+Ly β , and a single Gaussian component for all other lines as they are either too blended with these prominent lines (e.g. N V which is blended with Ly α), or too weak (e.g. N III] λ 1750) to justify more than one component. The nonlinear χ^2 minimization required to make the multiple Gaussian fit to the data is done using the *Levenberg-Marquardt* method, as implemented by the MRQMIN routine described in *Numerical Recipes* (Press *et al.* 1989). The number of Gaussian components used to model the profile of each line is the minimum number of components required for an “acceptable fit”, where an “acceptable fit” is defined as one which results in a reduced χ^2 of about 2 or smaller. We found that two Gaussian components are generally not enough to provide an “acceptable fit” for the prominent UV lines, while four components do not produce a significantly better fit than the one obtained with three components.

The major limitation of multiple Gaussian fits is that the best fit solution is not unique. The specific solution obtained depends on the initial values for the fit parameters, and it can include physically implausible parameters, such as a negative flux. It is therefore important to have a well defined procedure to obtain a “good” initial guess, i.e. initial values which will lead to a rapid convergence to an acceptable and stable solution. Below we define the process by which the initial parameters are obtained.

Note that the observed continuum is contaminated by narrow absorption lines. These absorption lines have been studied in detail by Bahcall *et al.* (1991, 1992a,b 1993a), and Morris *et al.* (1991), who identified a well defined set of absorption lines. Here, however, we wish to avoid identifying a region as free of absorption even when it is only suspected of being absorbed, and we therefore adopt a lower significance level for the purpose of identifying spectral regions which are possibly affected by absorption.

The line fitting is done according to the following algorithm:

1. Smooth the data using a Gaussian with $\Sigma = 1.75$ pixels (which is approximately the width of the spectral line spread function). This allows weak unresolved absorption features to be more easily detected, with a loss of spectral resolution which is insignificant for our broad emission line study.
2. Identify regions which are possibly affected by absorption as follows:
 - a. Use a median filter with a width of 21 pixels to get an initial estimate for the local intrinsic emission level F_{λ}^{med} . This smoothing effectively eliminates all spectral features narrower than $\sim 600 \text{ km s}^{-1}$.

- b. Delete all pixels with $\Delta < \Delta_{\text{threshold}}$, and their neighboring three pixels, where $\Delta \equiv (F_{\lambda}^{\text{ob}} - F_{\lambda}^{\text{med}})/\sigma$. F_{λ}^{ob} is the Gaussian smoothed observed flux, σ is the measurement error, and $\Delta_{\text{threshold}} = -2.5$.
 3. Subtract the underlying continuum flux from F_{λ}^{ob} to obtain the line flux F_{λ}^l . The continuum flux is given by $F_{\lambda}^c = F_{\lambda_1}^{\text{med}}(\lambda/\lambda_1)^{\beta}$, where $\beta = \ln(F_{\lambda_1}^{\text{med}}/F_{\lambda_2}^{\text{med}})/\ln(\lambda_1/\lambda_2)$, and λ_1, λ_2 are the two end points of the fitted section of the spectrum.
 4. Obtain initial values for the Gaussian parameters as follows:
 - a. Measure the first three moments (i.e. 0th, 1st and 2nd moments) of the flux distribution within the lower portion of the line. This portion is defined as $F_{\lambda}^1 \equiv \min(F_{\lambda}^l, 0.1 \times F_{\lambda}^{\text{max}})$, where $F_{\lambda}^{\text{max}} = \max(F_{\lambda}^l)$ for $\lambda_1 \leq \lambda \leq \lambda_2$. The three moments define the initial values for the first Gaussian component, which provides an approximate fit to the base of the line.
 - b. Subtract the first Gaussian component from F_{λ}^l to get $F_{\lambda}^{l'}$. Measure the first three moments of the flux distribution within the middle part of the line defined as $F_{\lambda}^2 \equiv \min(F_{\lambda}^{l'}, 0.7 \times F_{\lambda}^{1,\text{max}})$, within $|\lambda - \lambda_0| < 20 \text{ \AA}$, where $F_{\lambda}^{1,\text{max}} = \max(F_{\lambda}^{l'})$ for $|\lambda - \lambda_0| < 20 \text{ \AA}$, and λ_0 is the wavelength of the observed line peak. These three moments define the initial values for the second Gaussian components.
 - c. Subtract the second Gaussian component from the data and measure the first three moments of the remaining flux at $|\lambda - \lambda_0| < 5 \text{ \AA}$. These define the third Gaussian component, which approximately fits the line peak.
- This completes the determination of the initial values of the three Gaussians used to model the profiles of the prominent line. The initial values for other blended components are determined as follows:
- d. Measure the first three moments of F_{λ}^l within $|\lambda - \lambda_i| < 10 \text{ \AA}$, where λ_i is the rest wavelength of the blended line i .
 - e. Repeat d for all additional blended lines (up to three blended lines were required in our analysis).

5. Run the nonlinear χ^2 minimization routine MRQMIN to allow the initial guess for the Gaussian components to relax into the best fit solution which minimizes the fit χ^2 .

We thus fit each prominent line with three Gaussians which describe the base, the middle portion, and the core of the line. Note that the value of the fit χ^2 serves only as a qualitative measure of the fit and should not be interpreted as indicating the probability of the fit. This is because our data are characterized by a rather high S/N (~ 60), and systematic calibration errors

of the order of the statistical error σ (mostly determined by the number of photons) are likely to be present in the spectra. The χ^2 would also be increased if weak absorption features, which could not be clearly identified, are common. One should also note that this fitting procedure cannot fit small amplitude narrow features away from the positions of the peaks.

Gaussians do not form a complete set of orthogonal functions and therefore the specific decomposition obtained here is not unique. The algorithm given above is, however, well defined, and leads to one specific solution which depends only on the given form of F_λ^l .

The nonorthogonality of the individual Gaussian components results in a strong covariance of the errors of the fit parameters. We therefore do not use the χ^2 minimization routine to quantify the parameter errors, but rather present the parameters obtained by the algorithm described above as a specific “acceptable fit”. The placement of the continuum level is a possible source for a large systematic error, and this placement is largely subjective. To get a rough estimate of the possible errors introduced by the continuum placement, we repeat the line-fitting procedure described above two more times for each blend. In the first iteration we set the continuum level at $F_{\lambda_1}^{\text{med}} + \sigma_{\lambda_1}^{\text{med}}$ and $F_{\lambda_2}^{\text{med}} + \sigma_{\lambda_2}^{\text{med}}$, where $\sigma_{\lambda_i}^{\text{med}}$ is the median of the 21 flux errors in the 21 pixels wide continuum window (note that the formal error in the median is $\sim \sigma^{\text{med}}/\sqrt{21}$, but correlated systematic errors are likely to be present). In the second iteration, the continuum is set at $F_{\lambda_1}^{\text{med}} - \sigma_{\lambda_1}^{\text{med}}$ and $F_{\lambda_2}^{\text{med}} - \sigma_{\lambda_2}^{\text{med}}$. These two additional runs are used to estimate the possible range in the values of all the fit parameters. This range is typically not symmetric around the best fit parameters, and occasionally the two additional runs give values which deviate from the best fit value in the same direction.

A.3. *Alternative Line-Shape parameterization Methods*

The most straightforward parameterization of the line shape is through the moments of the flux distribution within the line. The determination of these moments is subject to a large error beyond the second moment (the velocity dispersion), as the higher moments are mostly determined by the far wings of the line where the S/N approaches zero. Other simple line profile parameterization schemes were described by various authors, e.g., Whittle (1985), Boroson & Green (1992), Emmering *et al.* (1992). However, these various parameterizations are physically meaningful only for unblended lines, and such lines are not available here.

A very similar but simpler method to parameterize the line shape is to measure directly the first three moments of the flux distribution within the base, middle, and core sections of the line, as done above but without applying the detailed model fitting scheme described above (through the χ^2 minimization). This method yields results which are very similar to the those obtained above following the model fitting if: 1. the observed profile is characterized by a high S/N, 2. the observed profile is not significantly affected by absorption. However, significant narrow absorption

features are present in many parts of the spectrum, and our line fitting method identifies these regions and excludes them from the fit. Our method thus allows a more reliable estimate of the intrinsic emission line shape parameters.

The non-uniqueness of our Gaussian decomposition method can be overcome if the line profiles are modeled using a complete set of orthogonal functions. For example, van der Marel & Franx (1992) use the first few terms in the Gauss-Hermite series to quantify the shape of isolated stellar absorption lines in spectra of galaxies. This method is mostly suitable for unblended lines. In our case, all lines are blended, and an acceptable fit will require a large number of terms in the series expansion. Furthermore, the individual expansion terms do not have a straightforward physical interpretation when the fit is made to blended lines.

A.4. *Line Deblending Using a Template*

Earlier studies (e.g. Baldwin & Netzer 1978; Uomoto 1984) have generally deblended emission lines using the observed profile of one of the prominent lines, typically C IV, as a template for the other line profiles. This method has two major drawbacks: 1. It relies on the presence of strong unblended lines, while as shown below, all strong emission lines are blended to various degrees. 2. The basic premise that all lines have similar profiles is not necessarily valid.

Some of the emission lines are multiplets of two or more components (e.g C IV, N V, O VI), and it is not clear whether the apparent profile differences reflect intrinsic differences in the velocity distribution of the line emitting gas. The only way to test the significance of the profile differences is through template fitting. The best ad hoc solution we found to the first drawback mentioned above is using the blue wing of Ly α , and assuming Ly α is intrinsically exactly symmetric. The second drawback is avoided since our purpose here is in fact to test the significance of the profile differences. If a template fit is determined to be acceptable then it can be used to deblend the parameters (flux and velocity shift) of the individual lines.

We fit the various observed emission blend profiles with a sum of “symmetric Ly α ” templates. We use one template component for each line, or if the line is a multiplet, one template component for each multiplet component (e.g., two for C IV). The flux normalization and velocity shift of each component are free parameters. However, the velocity differences between components of a multiplet is fixed (e.g. 498.7 km s⁻¹ for C IV), and the flux ratio in components of a multiplet is fixed at either the statistical weight ratio (e.g. 2:1 for C IV), or at a ratio of 1. We then look for the parameters of the best fit solution, i.e. the solution which minimizes the fit χ^2 . The χ^2 minimization is done using the MRQMIN, as described §A.2.

When this method is successful in producing an acceptable fit, it most probably gives a significantly more realistic measurement of the flux in the various lines contributing to the emission blend, as compared with the Gaussian components fittings. We note, however, that some lines

(e.g., C III]) are often significantly different from $\text{Ly}\alpha$, and in some objects (e.g. H1821+643) all lines are clearly asymmetric. In all these cases the template method cannot be applied.

REFERENCES

- Atwood, B., Baldwin, J. A., & Carswell, R. F. 1982, *ApJ*, 257, 559
- Bahcall, J. N. 1966, *ApJ*, 145, 684
- Bahcall, J. N., & Sargent, W. L. W. 1967, *ApJ*, 148, L65
- Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., Hartig, G. F., Bohlin, R., & Junkkarinen, V. 1991, *ApJ*, 377, L5
- Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., Hartig, G. F., & Green, R. F. 1992a, *ApJ*, 397, 68
- Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., Hartig, G. F., & Jenkins, E. B. 1992b, *ApJ*, 398, 495
- Bahcall, J. N., Jannuzi, B. T., Schneider, D. P., & Hartig, G. F. 1993a, *ApJ*, 405, 491
- Bahcall, J. N., Bergeron, J., Boksenberg, A., Hartig, G. F., Jannuzi, B. T., Kirhakos, S., Sargent, W. L. W., Savage, B. D., Schneider, D. P., Turnshek, D. A., Weymann, R. J., & Wolfe, A. M., 1993b, *ApJS*, in press
- Baldwin, J. A., McMahon, R., Hazard, C., & Williams, R. E. 1988, *ApJ*, 327, 103
- Baldwin, J. A., & Netzer, H. 1978, *ApJ*, 226, 1
- Boroson, T. A. & Green, R. F., 1992, *ApJS*, 80, 109
- Boyle, B. J. 1990, *MNRAS*, 243, 231
- Buson, L. M. & Ulrich, M. H. 1990, *A&A*, 240, 247
- Burstein, D. & Heiles, C., 1982, *ApJ*, 87, 1165
- Capriotti, E., Foltz, C., & Byard, P. 1981, *ApJ*, 245, 369
- Collin-Souffrin, S., Dyson, J. E., McDowell, J. C., & Perry, J. J. 1988, *MNRAS*, 232, 539
- Corbin, M. R. 1990, *ApJ*, 357, 346
- Cristiani, S. & Vio, R. 1990, *A&A*, 227, 385
- Dumont, A. M., & Mathez, G. 1981, *A&A*, 102, 1
- Dumont, A. M., & Collin-Souffrin, S. 1990, *A&A*, 229, 313
- Emmering, R. T., Blandford, R. D., & Shlosman, I. 1992, *ApJ*, 385, 460
- Ferland, G. J., K. T. Korista, & Peterson, B. M. 1990, *ApJ*, 363, L21
- Ferland, G. J., Netzer, H., & Shields, G. A. 1979, *ApJ*, 232, 382
- Ferland, G. J., & Persson, S. E. 1989, *ApJ*, 347, 656
- Ferland, G. J., Peterson, B. M., Horne, K., Welsh, W. F. & Nahar, S. N. 1992, *ApJ*, 387, 95
- Francis, P. J., Hewett, P. C., Foltz, C. B., Chaffee, F. H., Weymann, R. J., & Morris, S. 1991, *ApJ*, 373, 465
- Gaskell, C. M. 1982, *ApJ*, 263, 79
- Gaskell, C. M., Shields, G. A., & Wampler, E. J. 1981, *ApJ*, 249, 443
- Gondhalekar, P. M., O'Brien, P., & Wilson, R. 1986, *MNRAS*, 222, 71
- Grandi, S. A., & Phillips, M. M. 1979, *ApJ*, 232, 659
- Green, R. F., Pier, J. R., Schmidt, M., Estabrook, F. B., Lane, A. L., & Wahlquist, H. D. 1980, *ApJ*, 239, 483

- Hamann, F., & Ferland, G. 1992, ApJ, 391, L53
- Kallman, T. R., & Krolik, J. H. 1986, ApJ, 308, 805
- Kallman, T. R., Wilkes, B. J., Krolik, J. H., & Green, R. 1993, ApJ, 403, 45
- Kinney, A. L., Bohlin, R. C., Blades, J. C., & York, D. G. 1991, ApJS, 75, 645
- Kinney, A. L., Huggins, P. J., Bergman, J. N. & Glassgold, A. E. 1985, ApJ, 291, 128
- Kinney, A. L., Huggins, P. J., Glassgold, A. E. & Bergman, J. N. 1987, ApJ, 314, 145
- Kolman, M., Halpern, J. P., Shrader, C. R. & Filippenko, A. V. 1991, ApJ, 373, 57
- Koratkar, A. P. & Gaskell C. M. 1991, ApJ, 375, 85
- Korista, K. T., Weymann, R. J., Morris, S. L., Kopko, M., Turnshek, D. A., Hartig, G. F., Foltz, C. B., Burbidge, E. M., & Junkkarinen, V. T. 1993, ApJ, 401, 529
- Kriss, G. A., Davidsen, A. F., Blair, W. P., Ferguson, H. C., & Long, K. S. 1992, ApJ, 394, L37
- Kwan, J. 1984, ApJ, 283, 70
- Kwan, J., & Krolik, J. H. 1981, ApJ, 250, 478
- Laor, A., & Draine, B. T. 1993, ApJ, 402, 441
- Maoz D., Netzer, H., Mazeh, T., Beck, S., Almoznino, E., Leibowitz, E., Brosch, N., Mendelson, H., & Laor, A. 1991, ApJ, 367, 493
- Morris, S. L., Weymann, R. J., Savage, B. D., & Gilliland, R. L. 1991, ApJ, 377, L21
- Morton, D. C., 1991, ApJS, 77, 119
- Netzer, H. 1990, in Active Galactic Nuclei (SAAS-FEE Advanced Course 20, Swiss Society for Astrophysics and Astronomy), ed. Courvoisier T. J. L., & Mayor M. (Berlin: Springer), 57
- Netzer, H., & Laor, A. 1993, ApJ, 404, L51
- Netzer, H., Laor, A., & Gondhalekar, P. M. 1992, MNRAS, 254, 15
- Netzer, H., & Wills, B. J. 1983, ApJ, 275, 445
- O'Brien, P. T., Gondhalekar, P. M. & Wilson, R., 1988, MNRAS, 233, 801
- Osmer, P. A., & Smith, M. G. 1976, ApJ, 210, 267
- Osterbrock, D. E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei, (California, University Science Books)
- Peterson, B. M. 1993, PASP, 105, 247
- Peterson, B. M., Ali, B., Horne, K., Bertram, R., Lane, N. J., Pogge, R. W. & Wagner, R. M. 1993, ApJ, 402, 469
- Press, W. H., Flannery, B. P., Teukolsky, S. A., & Vetterling, W. T. 1989, "Numerical Recipes: The Art of Scientific Computing", (Cambridge University Press)
- Rees, M. J., Netzer, H., & Ferland, G. J., 1989, ApJ, 347, 640
- Savage, B. D. *et al.* 1993, ApJ, submitted
- Savage, B. D. & Mathis, J. S. 1979, ARAA, 17, 73
- Schneider, D. P. *et al.* 1993, ApJS, in press
- Seaton, M. J., 1979. MNRAS, 187, 73p
- Shields, G. A. 1976, ApJ, 204, 330
- Shields, G. A. & McKee, C. F. 1981, ApJ, 246, L57

- Sofia, U. J., Bruhweiler, F. C., & Kafatos, M. 1988, in *A Decade of UV Astronomy with IUE*, ESA SP-281, Vol.2, 269
- Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., Linke, R. A., Heiles, C., & Hurwitz, M., 1992, *ApJS*, 79, 77
- Steidel, C. C. & Sargent, W. L. 1987, *ApJ*, 313, 171
- Steidel, C. C. & Sargent, W. L. 1991, *ApJ*, 382, 433
- Tinggui, W., Clavel, J., & Wamsteker, W. 1992, in *Physics of Active Galactic Nuclei*, eds. W. J. Duschl & S. J. Wagner (Springer-Verlag, Berlin), 261
- Tytler, D., & Fan, X. M. 1992, *ApJS*, 79, 1
- Ulrich, M. H. 1989, *A&A*, 220, 71
- Ulrich, M. H. et al. 1980, *MNRAS*, 192, 561
- Uomoto, A. 1984, *ApJ*, 284, 497
- van der Marel, R. P. & Franx, M. 1993, *ApJ*, 407, 525
- Véron-Cetty, M. P., Véron, P. 1991, “A catalogue of Quasars and Active Nuclei (5th Edition)” (Munich: European Southern Observatory)
- Véron-Cetty, M. P., Véron, P., & Tarengi, M. 1983, *A&A*, 119, 69
- Whittle, M. 1985, *MNRAS*, 213, 1
- Wilkes, B. J. 1984, *MNRAS*, 207, 73
- Wilkes, B. J. 1986, *MNRAS*, 218, 331
- Wilkes, B. J., & Carswell, R. F. 1982, *MNRAS*, 201, 645
- Wills, D., & Netzer, H. 1979, *ApJ*, 233, 1
- Wills, B. J., Netzer, H., & Wills, D. 1980, *ApJ*, 242, L1
- Wills, B. J., Netzer, H. & Wills, D. 1985, *ApJ*, 288, 94
- Wills, B. J., Netzer, Brotherton, M. S., Han, M., Wills, D., Baldwin, J. A., Ferland, G. J. & Browne, I. W. A. 1993, *ApJ*, in press
- Young, P., Sargent, W. L. W., & Boksenberg, A. 1982, *ApJS*, 48, 455

FIGURE CAPTIONS

Figure 1. The overall spectral shape of the five objects. Each panel shows the observed flux density *vs.* rest wavelength. The data were corrected for Galactic reddening, and for the purpose of presentation, the data were smoothed with a median filter of ~ 21 pixels (except near the prominent lines peaks). This smoothing effectively eliminates all spectral features narrower than 600 km s^{-1} , in particular the narrow absorption features present shortward of $\text{Ly}\alpha$. The thin line in each panel is the composite quasar spectrum of Francis *et al.* (1991) vertically shifted to overlap with the HST data at 1800 \AA . This composite was obtained from ground-based observations of a few hundred quasars at $z \sim 1 - 2$. Note the overall similarity between each spectrum and the composite, and the broad continuum feature at $\lambda \sim 1600 \text{ \AA}$ (especially in the spectrum of H1821+643).

Figure 2. Intercomparison of the five spectra. All spectra have been smoothed with a Gaussian with the width of the spectral resolution (see text). For clarity, all points with a negative deviation of more than 3σ , and the $\text{Ly}\alpha$ geocoronal line (its position marked with $\text{Ly}\alpha_{\oplus}$), were eliminated. We mark the positions of various lines that are expected to be present based on photoionization models, or that have been reported in other objects. In some cases, no feature is apparent at the marked position. Note the strong Galactic absorption on both sides of $\text{Ly}\alpha_{\oplus}$.

Figure 3. Deblending of the prominent emission lines. The Gaussian smoothed data in each panel is shown as an histogram. The nearly horizontal line at the bottom of each panel is the assumed continuum level. The other solid lines show the individual components and their sum. The small black triangles indicate points suspected of being affected by narrow absorption lines; these were not included in evaluating the fit χ^2 . The value of the fit χ^2 and the number of degrees of freedom are indicated in each panel (the value of χ^2 should not be interpreted in a formal statistical sense, see text). Note the overall smoothness of the cores of $\text{Ly}\alpha$ and C IV in most objects. **a.** PKS 0405–123; **b.** H1821+643; **c.** PG 0953+414; **d.** 3C273; **e.** Mrk 205.

Figure 4. $\text{Ly}\alpha$ and C IV blend asymmetries. Each panel displays the ratio of flux density in the red wing to the flux density in the blue wing of the fitted model to each blend as a function of velocity from line peak. H1821+643 and Mrk 205 have very asymmetric line profiles, but the other objects have rather similar asymmetries. Note that C IV is generally more symmetric than $\text{Ly}\alpha$. The dashed line indicates the expected ratio from isotropically emitting clouds distributed spherically symmetrically in both position and velocity. In this case special relativistic effects enhance the blue wing emission.

Figure 5. Comparison of the model fits to the profiles of the strongest lines. Each panel displays

the continuum subtracted line blend profiles, normalized to the line peak flux density, as a function of velocity from the expected rest frame position of the line peak. O VI is significantly broader than all other lines, Ly α is slightly narrower than C IV in all objects, and C III] has the narrowest peak of all broad lines (except in H1821+643). The low ionization H β line is only slightly shifted in all objects, and is generally significantly asymmetric. The narrow [O III] λ 5007 line of each object is also displayed. The peak of this line is used to define zero velocity.

Figure 6. Template fittings to the O VI, Ly α and the C IV blend. All blends were fitted with a sum of “symmetric Ly α ” profiles (see text). The thin line histogram is the observed blend profile, the thick line is the best fit model, and the dotted line is the fit for the O VI blend using a 1:1 flux ratio for the two components of the O VI doublet, rather than the statistical weight ratio. The vertical scale was normalized to unity at the peak of the model fit. The χ^2 of the fit, the number of degrees of freedom, and the velocity range over which the fit was made are indicated in each panel. In the O VI fit note the good match at $F_\lambda/F_{\text{max}} \sim 0.5$, and the excess flux in the observed red wing of O VI. In the Ly α fit note the generally very good match to red wing of the blend. In the C IV fit we also included contribution from the Si II λ 1531 doublet. Note the poor match near the peak of C IV, and the excess observed flux in the red wing of C IV.

Figure 7. Template fit to the Si IV+O IV] λ 1400 blend. The Si IV doublet is modeled as a sum of two components, and the O IV] multiplet as a sum of 5 components. Each component has the “symmetric Ly α ” profile, and the ratio of fluxes follows the ratio of statistical weights (see text). Both lines are assumed to have a zero velocity shift with respect to [O III] λ 5007. The Si IV/O IV] line ratios are indicated in each panel.